CMS101 ECAL

Seth Cooper University Of Minnesota

Overview

- Electron/photon energy deposition
- The CMS ECAL
- Construction
- Calibration and commissioning
- Physics Goals

ECAL Energy

- Electromagnetic Calorimetry

$e^{\pm}$ Energy—Calorimetry

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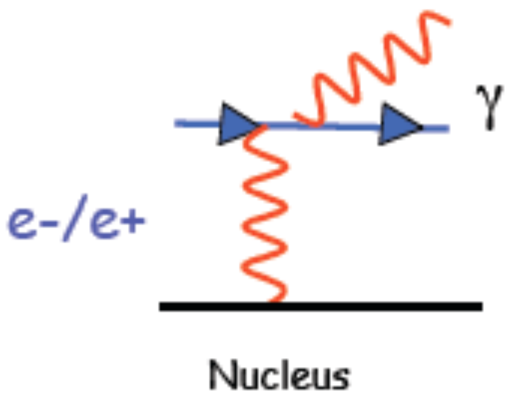
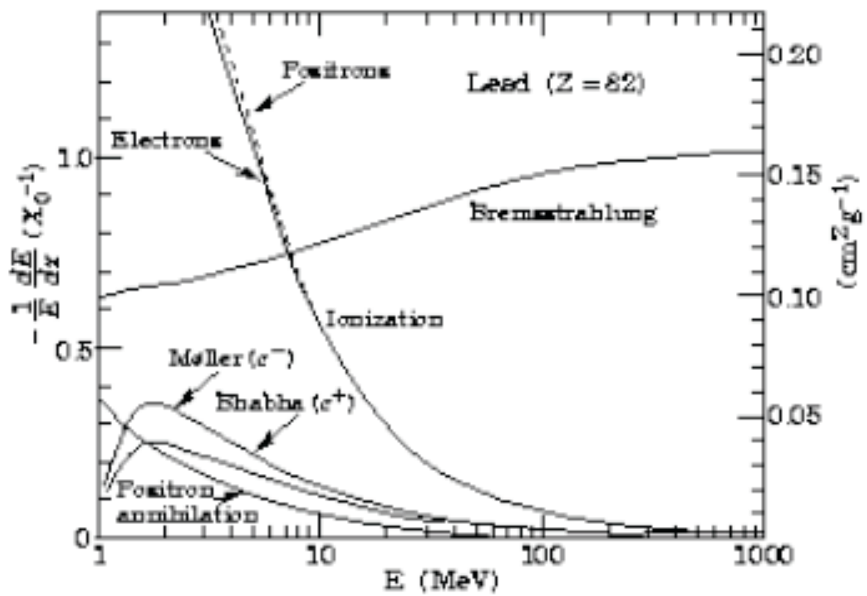
- Bremsstrahlung—(radiation of a photon)





$$\frac{dE}{dx} = -\frac{E}{X_0} \qquad X_0 = \frac{180A}{Z^2}$$

> - **Bremsstrahlung** dominates for energies above 20 MeV
> - The energy loss is governed by the radiation length X_o

Photon Energy—Calorimetry

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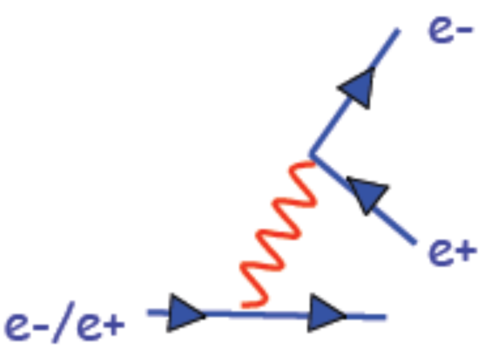
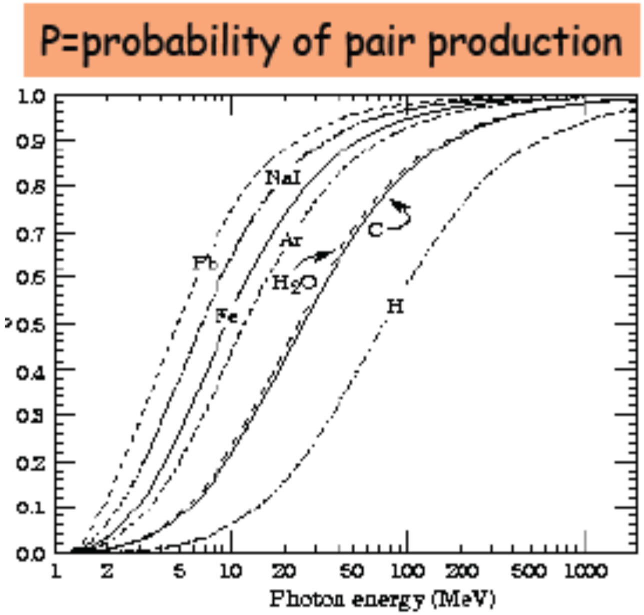
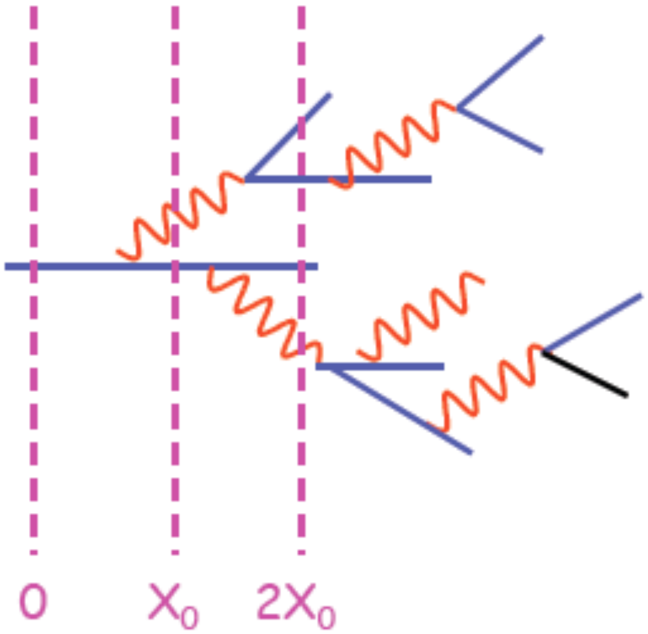
- Pair Production—e^+e^- production dominates





> **Pair production** dominates for energies above 20 MeV
>
> The energy loss is also governed by the radiation length X_o

The "Electromagnetic Shower"



- In general we can say
  - For each X_o, an electron loses ~63% of its energy to a photon
  - For each X_o, a photon splits its energy between an electron and positron
  - The depth of max energy deposition scales as the log of the energy:

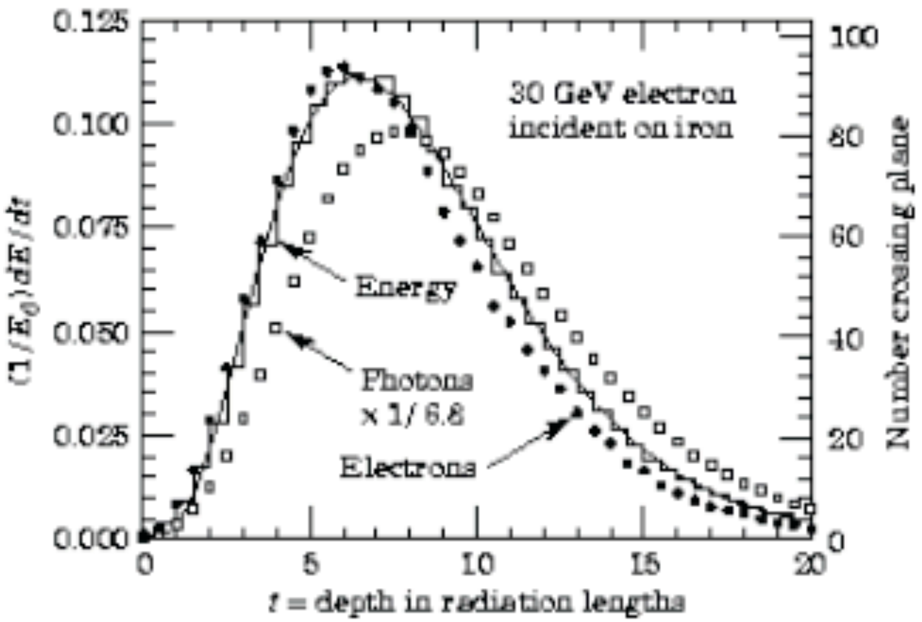
$$X_{max} \propto \ln(E_0 / E_c)$$

  - The total charged track length scales linearly with the energy:

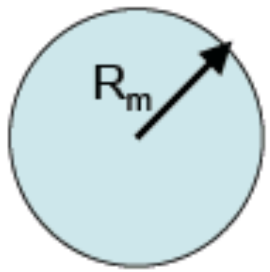
$$L \propto \frac{E_0}{E_c}$$

Shower Profile

Longtitudal Profile



Lateral Profile



Moliere Radius: $R_m \approx X_0$

(from multiple scattering)

To contain >99% shower need depth of material ~ 25 X_0

To measure lateral position accurately need segmentation ~ X_0

- The CMS ECAL

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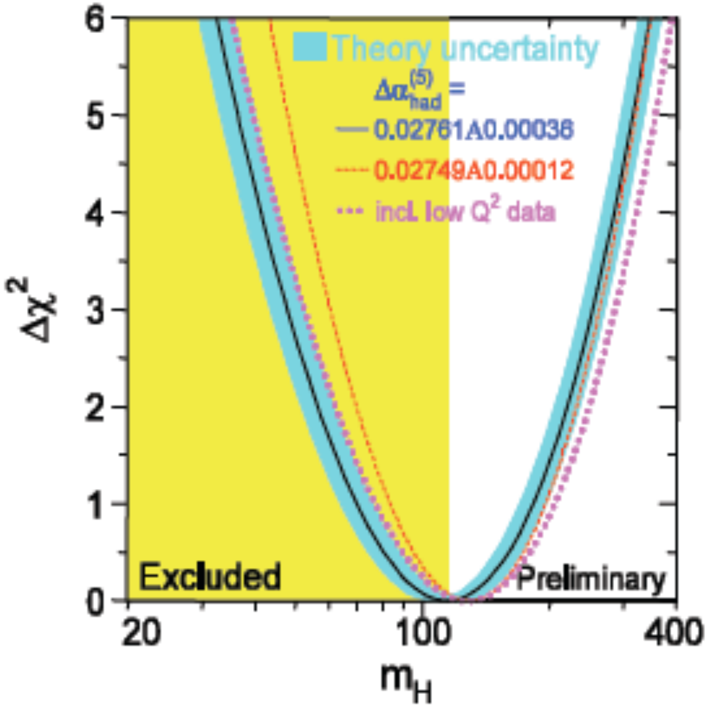
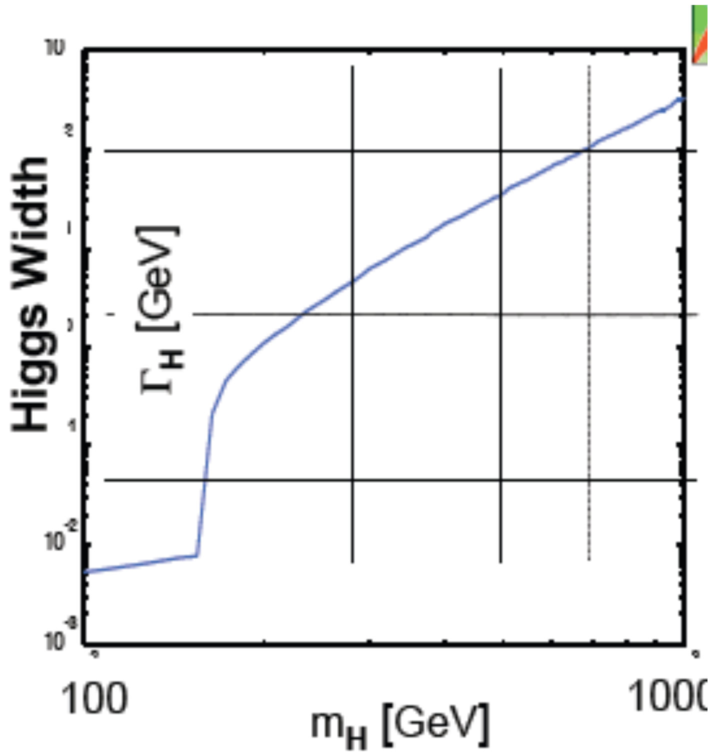
Higgs Decay Goal





- Low mass Higgs has the smallest width
  - Natural location to focus on

ECAL: Higgs → γγ Design Goal

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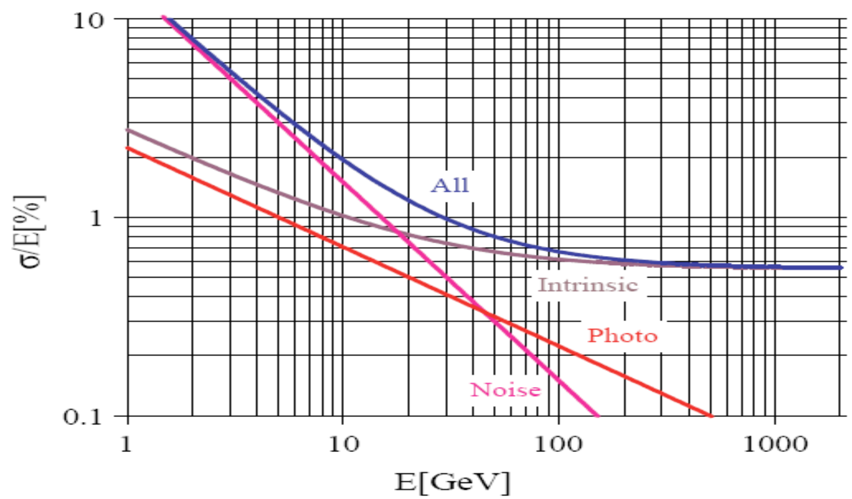
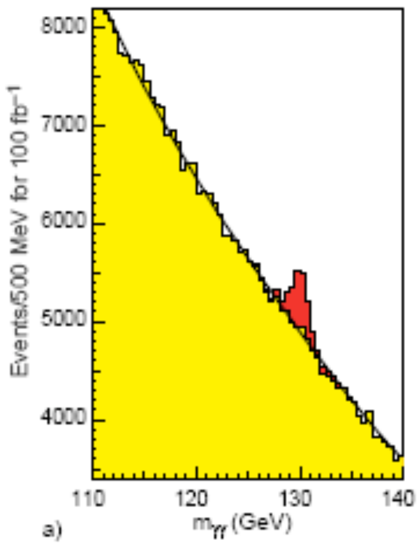
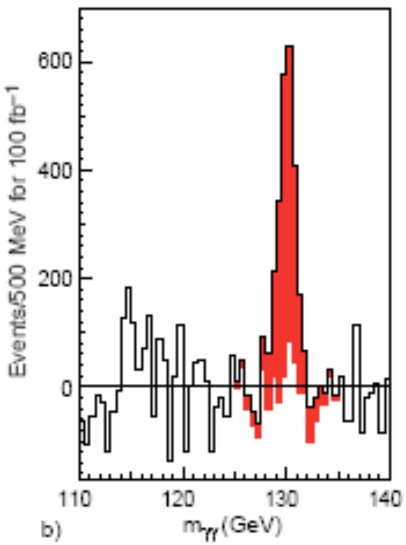
- The reconstructed mass of the Higgs depends on the energy of both photons as well as the angle between the two
- The error of the photon energy is very important

$$m_{\gamma\gamma}^2 = 2E_{\gamma 1}E_{\gamma 2}(1-\cos\theta_{\gamma 1,\gamma 2})$$

$$\frac{\sigma_{m_{\gamma\gamma}}}{m_{\gamma\gamma}} = \frac{1}{2}\left[\frac{\sigma_{E_{\gamma 1}}}{E_{\gamma 1}} \oplus \frac{\sigma_{E_{\gamma 2}}}{E_{\gamma 2}} \oplus \frac{\sigma_{\theta_{\gamma\gamma}}}{\tan(\theta_{\gamma\gamma}/2)}\right]$$



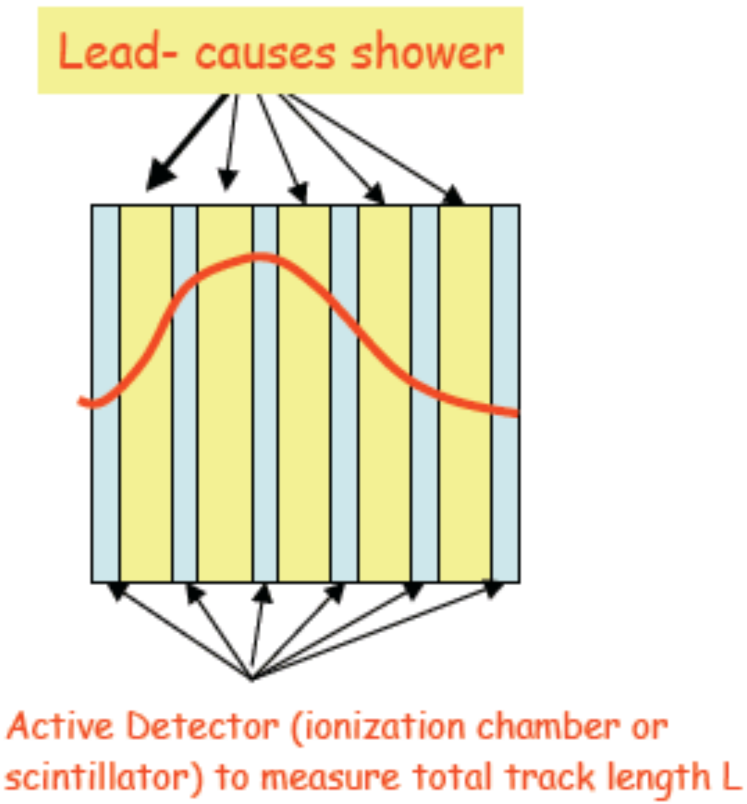




This significance is maximized by the energy resolution of the Ecal

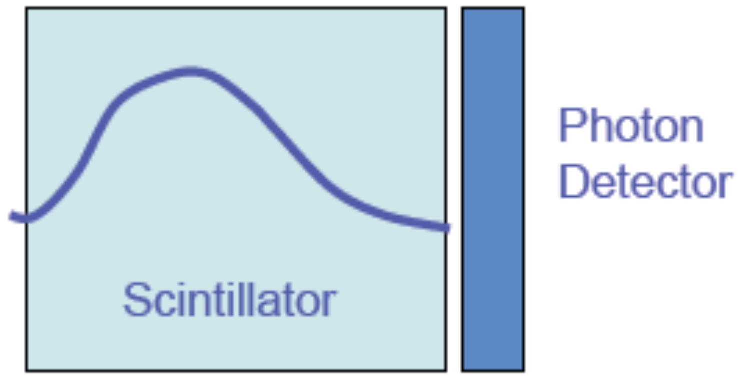
Must choose solid object

Sampling Calorimeter



Cheap with poor resolution
~2.5% for 100 GeV Photon

Total absorption calorimeter



Scintillator both causes shower and is active detector

Expensive with good Resolution ~0.5% at 100 GeV

$PbWO_4$ Crystals

- Lead Tungstate Crystals
  - Moliére radius: 2.2cm
  - Radiation Length: 0.89cm
  - Scintillation decay time: 80% at 35ns
  - Shown to be radiation resistant
  - -1.9%/°C temp dependence
- Lead Tungstate Crystals in CMS (Barrel)
  - "Average size", 2.4x2.4cm^2 and 23cm in length
  - 34 Different crystal shapes
  - 25.8 X_o

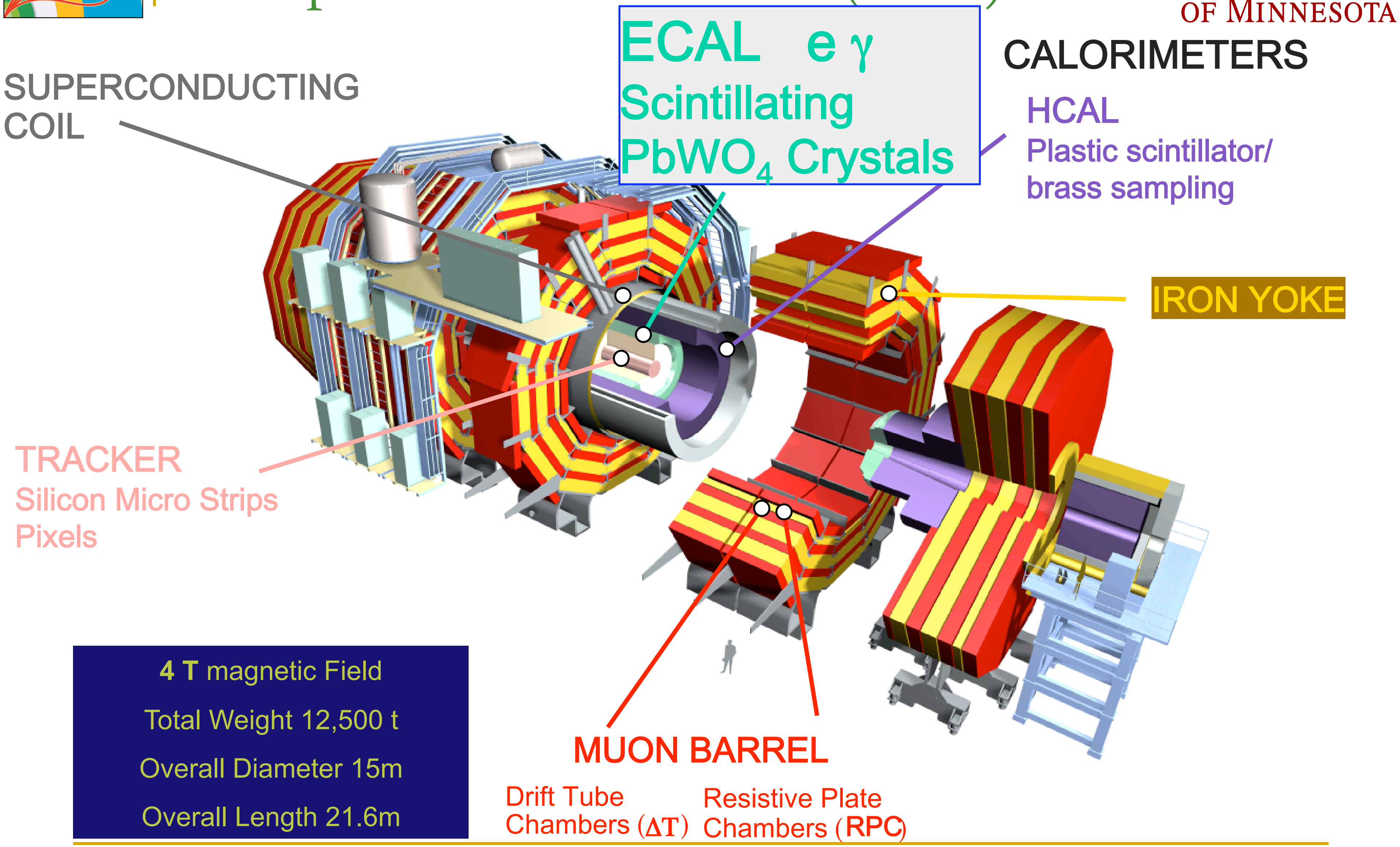
$PbWO_4$ Crystals

Experiment	C. Ball	L3	CLEO II	C. Barrel	KTeV	*BaBar*	BELLE	CMS
Accelerator	SPEAR	LEP	CESR	LEAR	FNAL	SLAC	KEK	CERN
Crystal Type	NaI(Tl)	BGO	CsI(Tl)	CsI(Tl)	CsI	CsI(Tl)	CsI(Tl)	$PbWO_4$
B-Field (T)	-	0.5	1.5	1.5	-	1.5	1.0	4.0
r_{inner} (m)	0.254	0.55	1.0	0.27	-	1.0	1.25	1.29
Number of Crystals	672	11,400	7,800	1,400	3,300	6,580	8,800	76,000
Crystal Depth (X_0)	16	22	16	16	27	16 to 17.5	16.2	25
Crystal Volume (m^3)	1	1.5	7	1	2	5.9	9.5	11
Light Output (p.e./MeV)	350	1,400	5,000	2,000	40	5,000	5,000	2
Photosensor	PMT	Si PD	Si PD	WS[a]+Si PD	PMT	Si PD	Si PD	APD[a]
Gain of Photosensor	Large	1	1	1	4,000	1	1	50
σ_N/Channel (MeV)	0.05	0.8	0.5	0.2	small	0.15	0.2	40
Dynamic Range	10^4	10^5	10^4	10^4	10^4	10^4	10^4	10^5

To comply with LHC and CMS conditions ECAL must be:

- fast
- compact
- highly segmented
- radiation resistant

Compact Muon Solenoid (CMS)



4 T magnetic Field

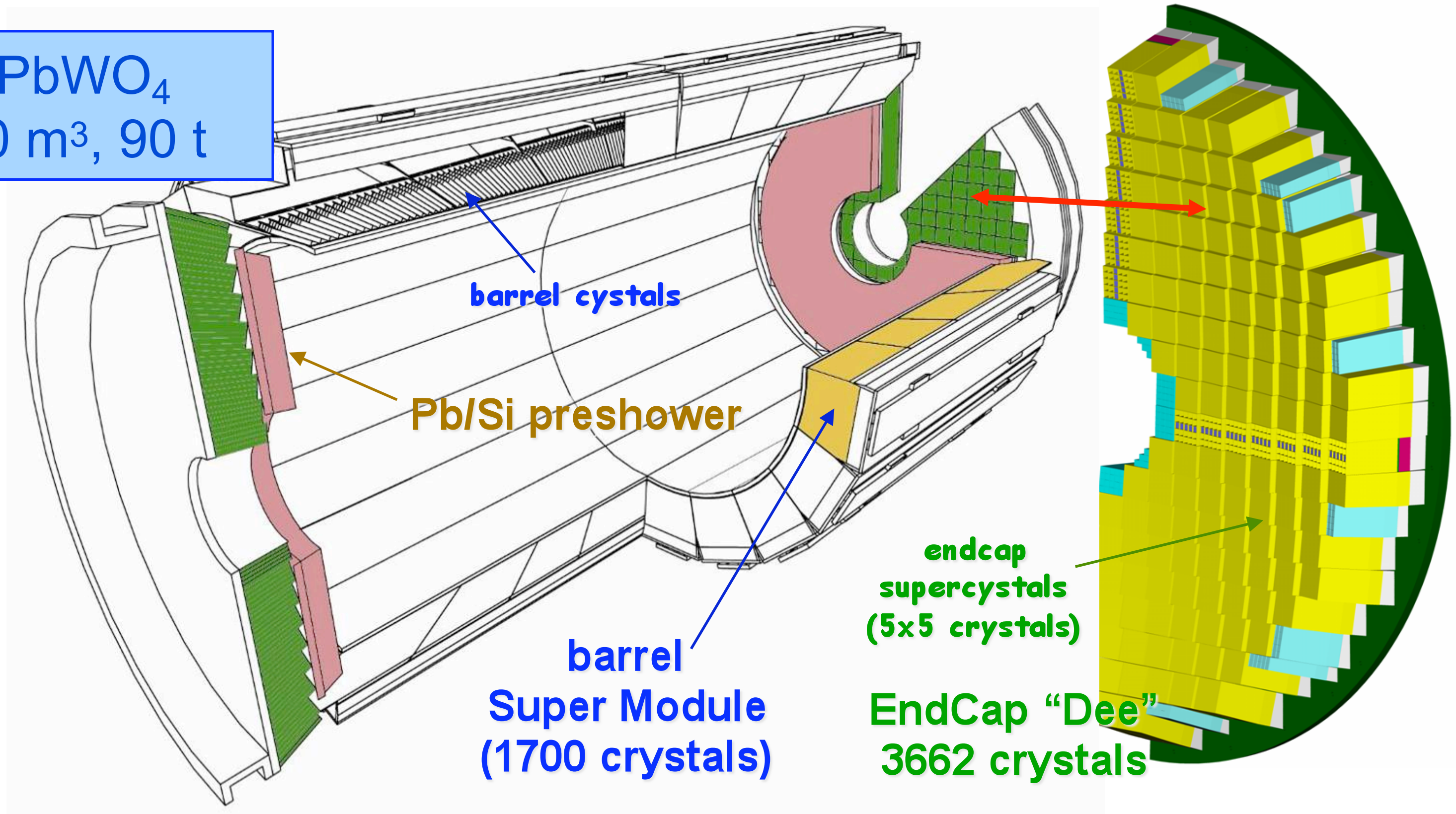
Total Weight 12,500 t

Overall Diameter 15m

Overall Length 21.6m

ECAL layout

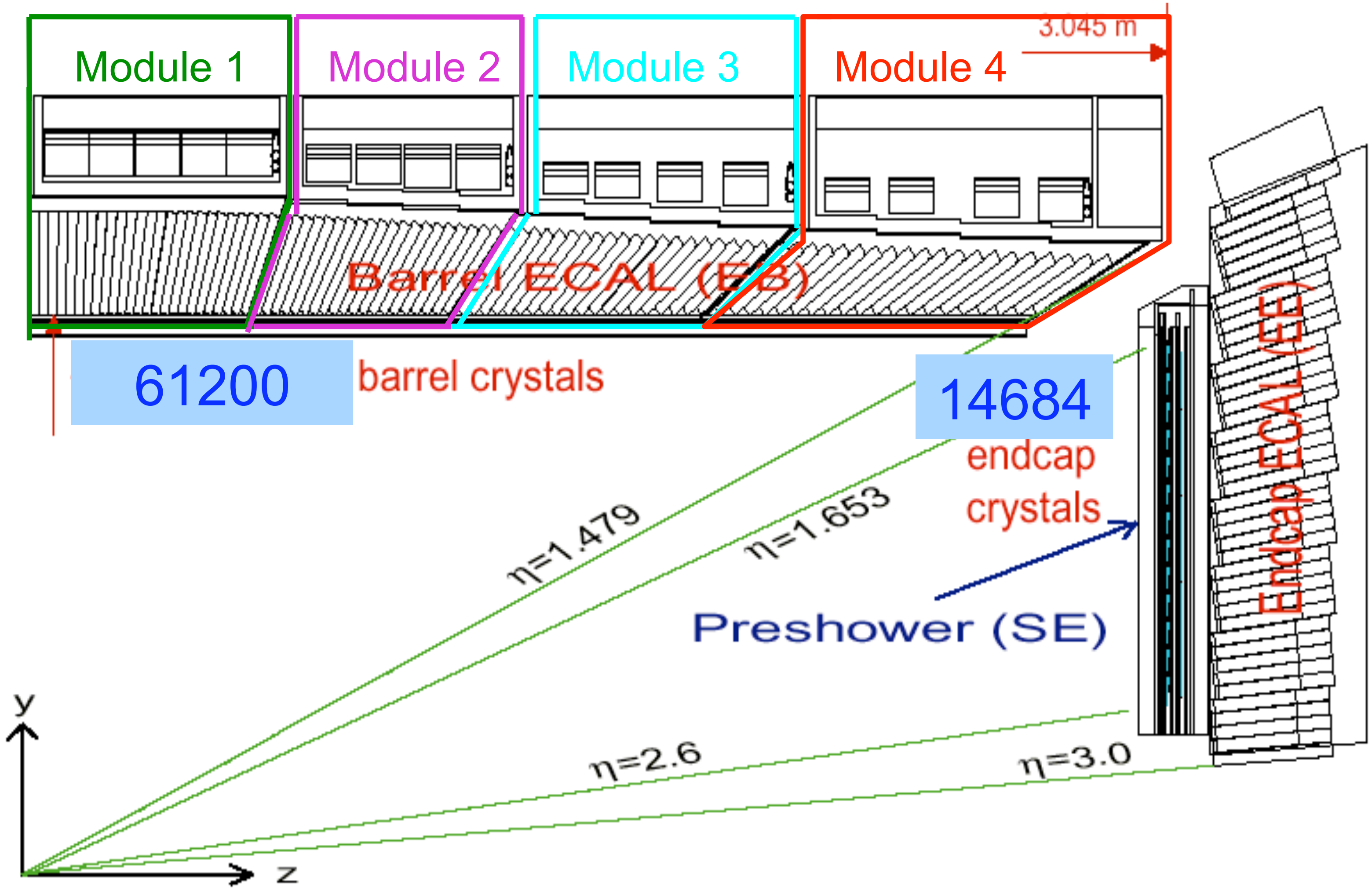
PWO: $PbWO_4$
about 10 m^3, 90 t



Barrel: $|\eta| < 1.48$
36 Super Modules
61200 crystals (2x2x23cm³)

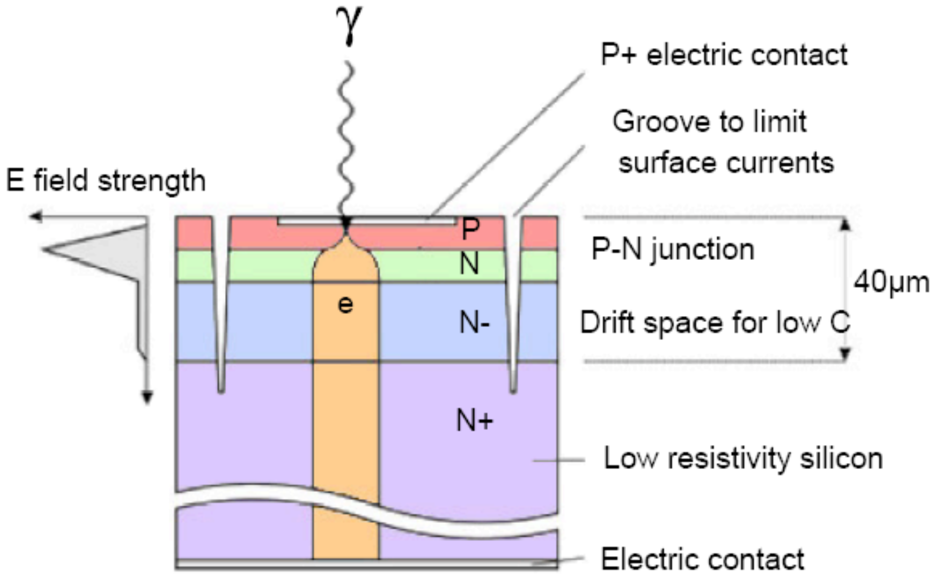
EndCaps: $1.48 < |\eta| < 3.0$
4 Dees
14648 crystals (3x3x22cm³)

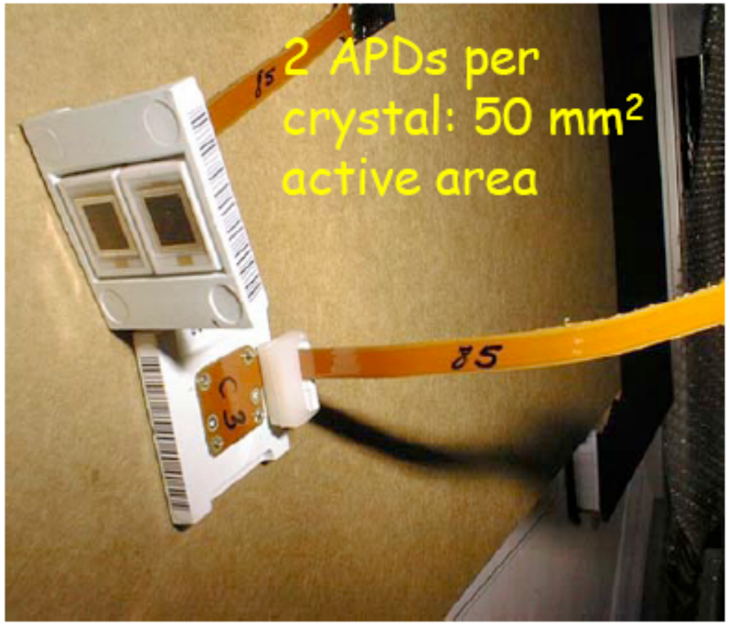
ECAL



Module 1
Module 2
Module 3
Module 4
3.045 m
Barrel ECAL (EB)
61200
barrel crystals
14684
endcap
crystals
η=1.479
η=1.653
Preshower (SE)
Endcap ECAL (EE)
η=2.6
η=3.0
y
z

ECAL Barrel Optical Readout





≈ 4.5 photo-electrons/MeV

122400 Total APD's

Very linear devices

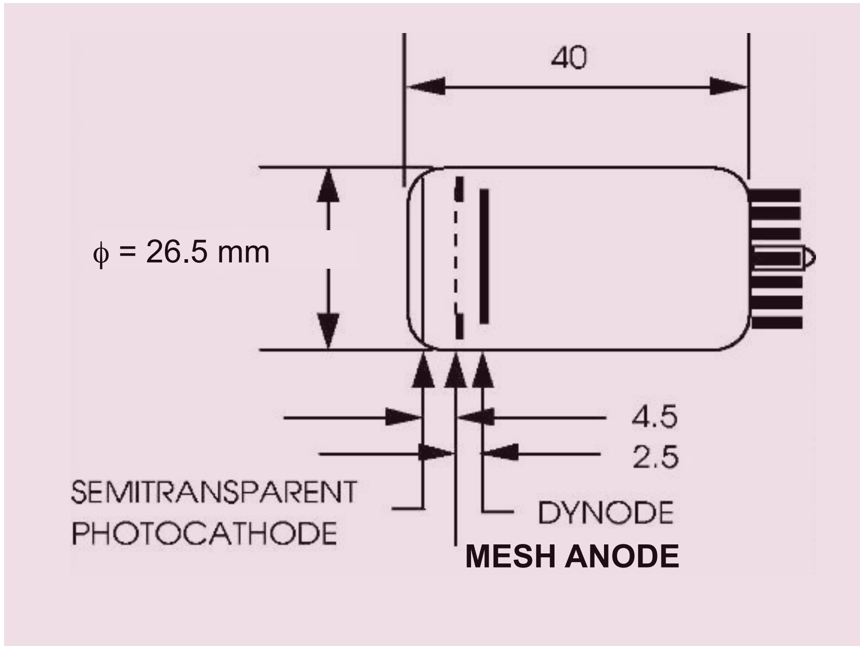
- Two 5x5 mm^2 APD's/crystal
- Gain – 50
- QE – 75% @ 420 nm
- Temp sensitivity – -2.4%/^{o}C

ECAL Endcap Photodetectors

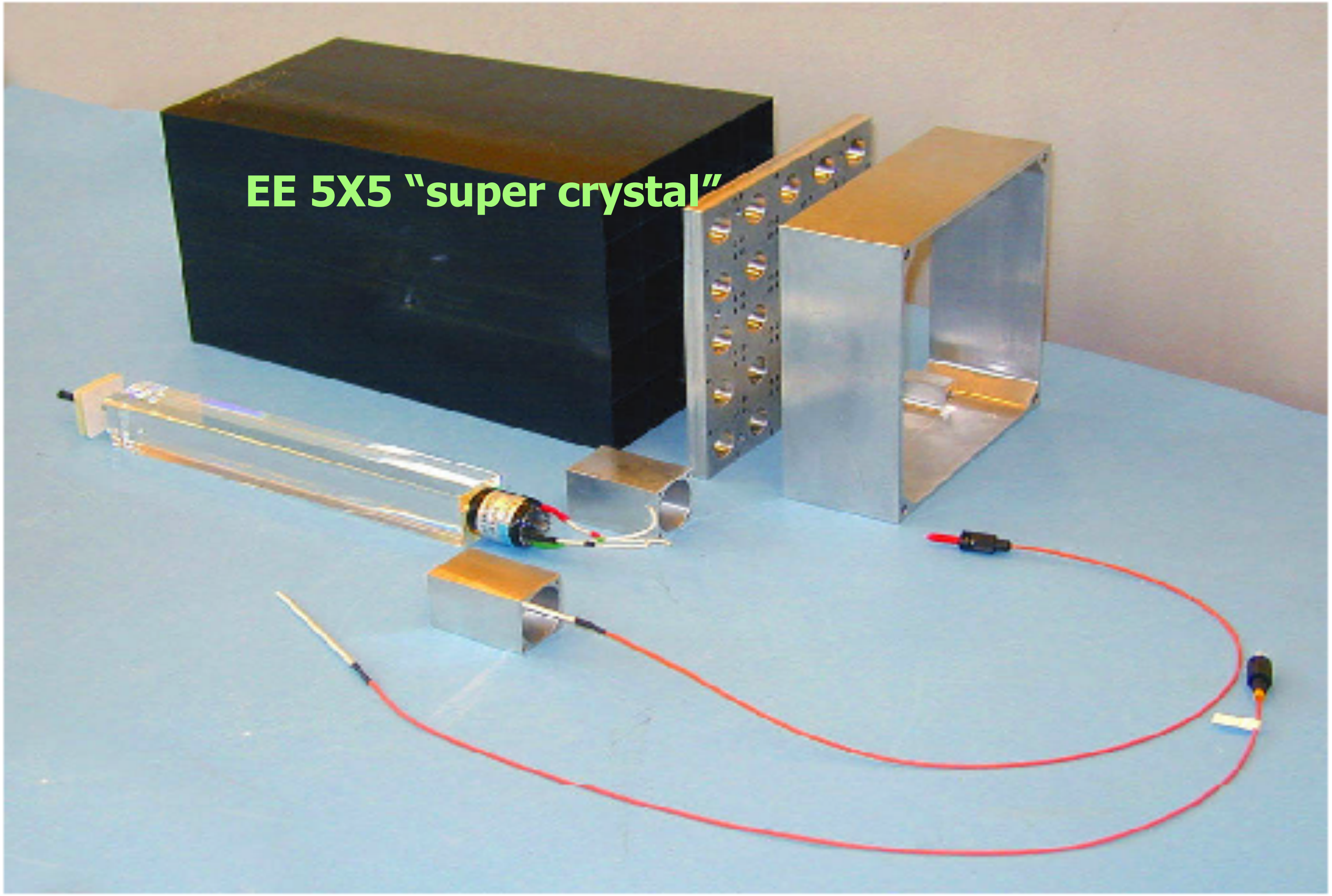
Endcaps: - Vacuum phototriodes (VPT)

More radiation resistant than Si diodes (with UV glass window)

- Active area ~ 280 mm^2/crystal
- Gain 8 -10 (B=4T)   Q.E.~20% at 420 nm



$PbWO_4$ Crystals for ECAL



On detector electronics

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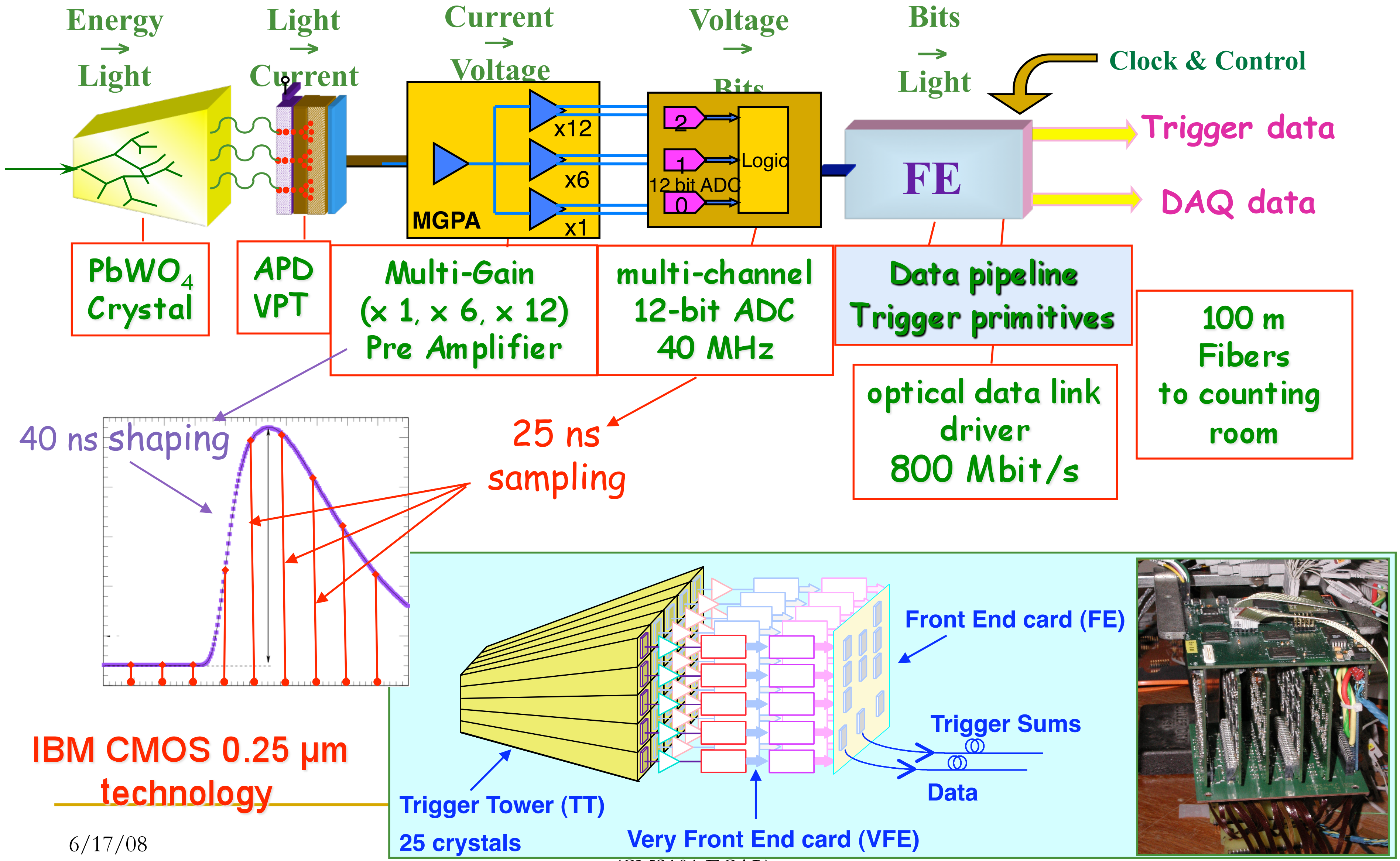
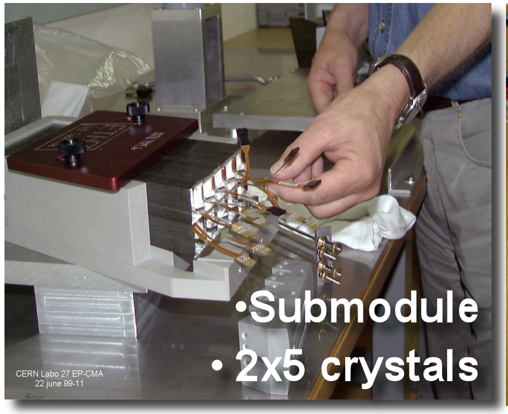
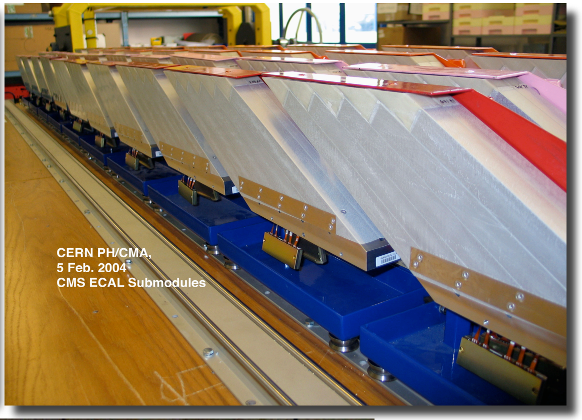
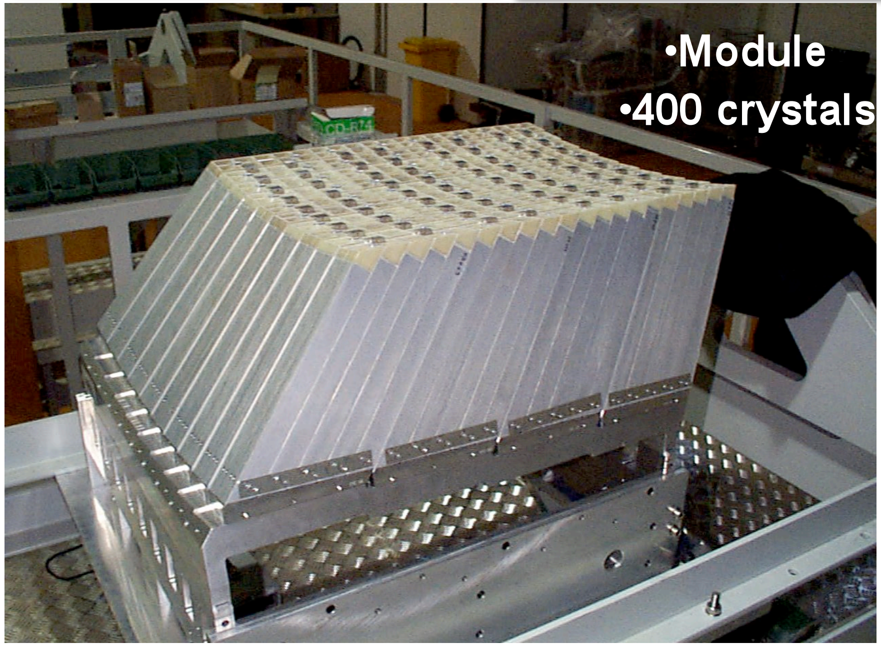
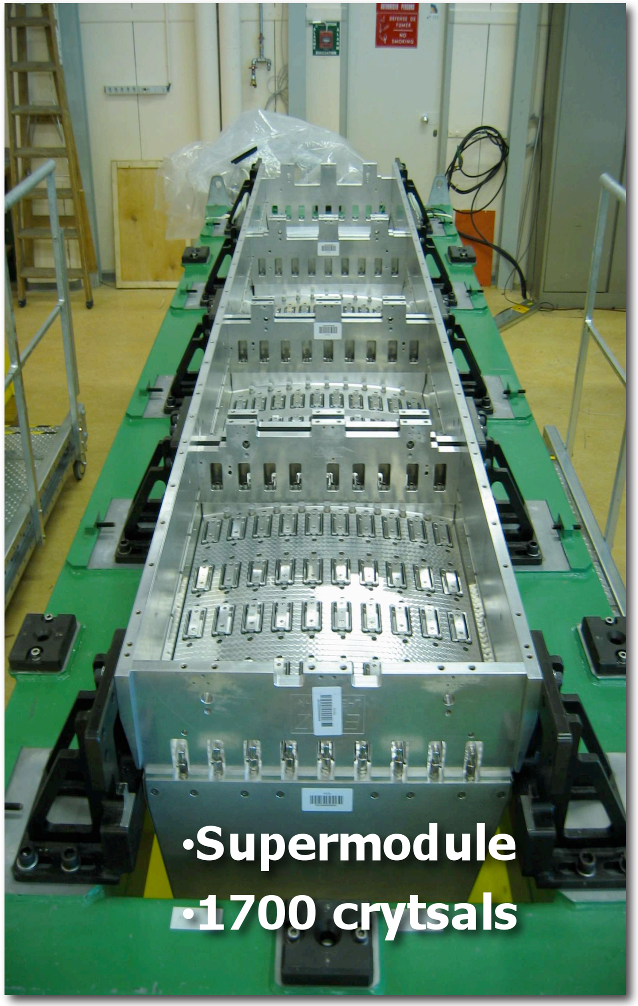


Assembly of ECAL



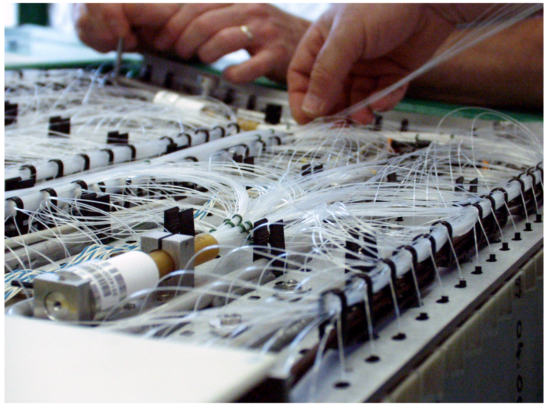


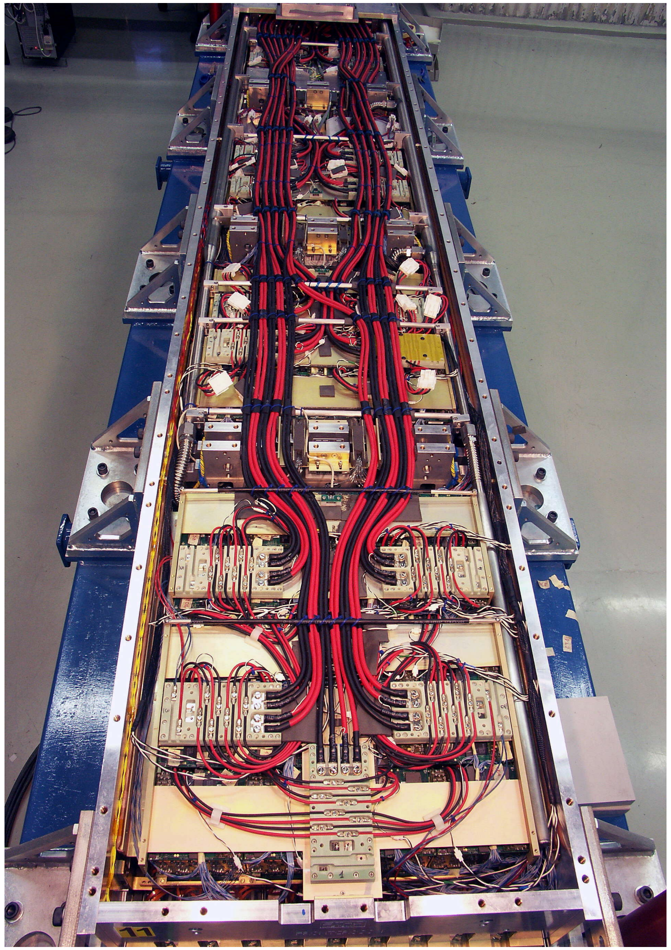




Total 36 Supermodules

SM Assembly





EB Factory

First SM in HCAL

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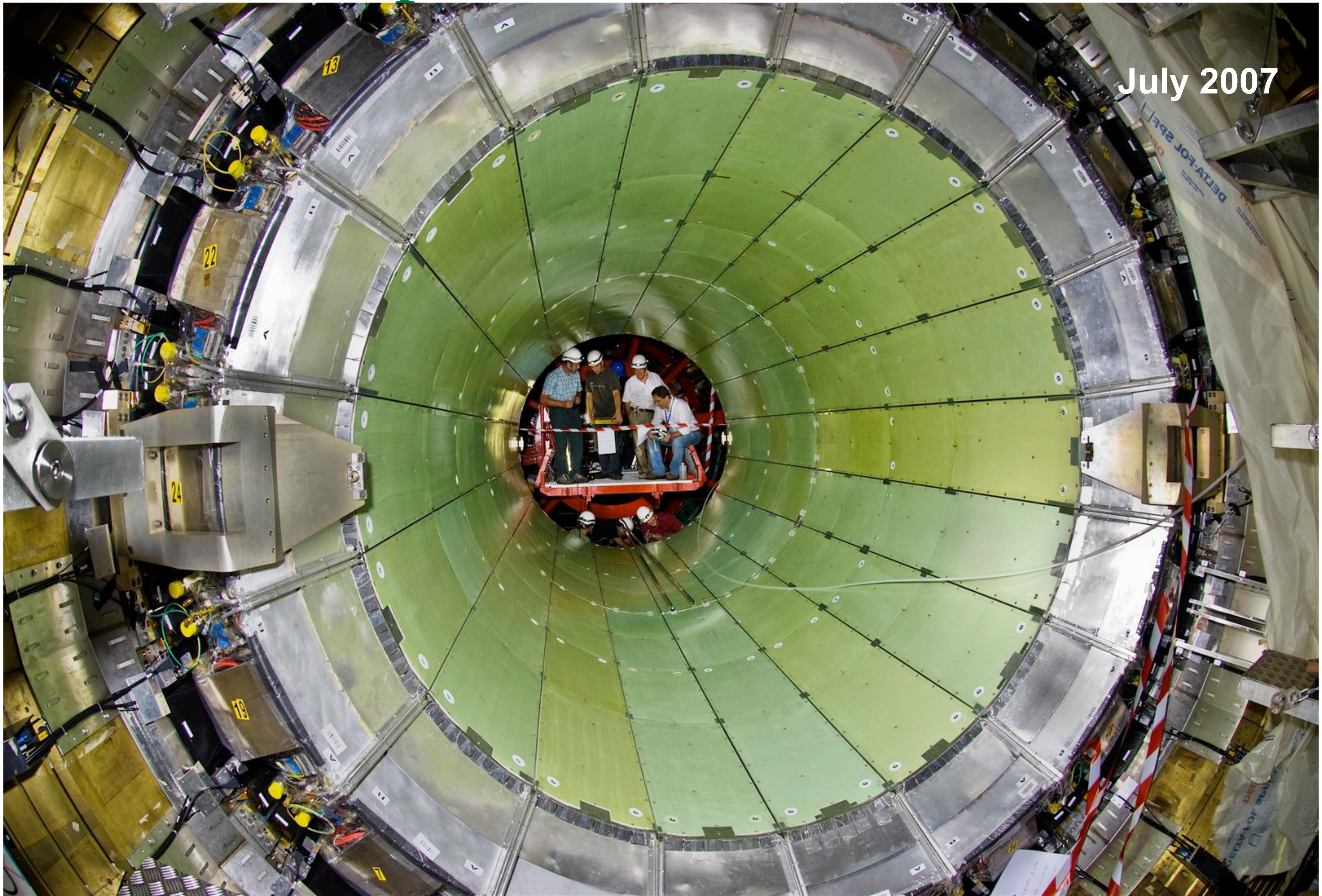
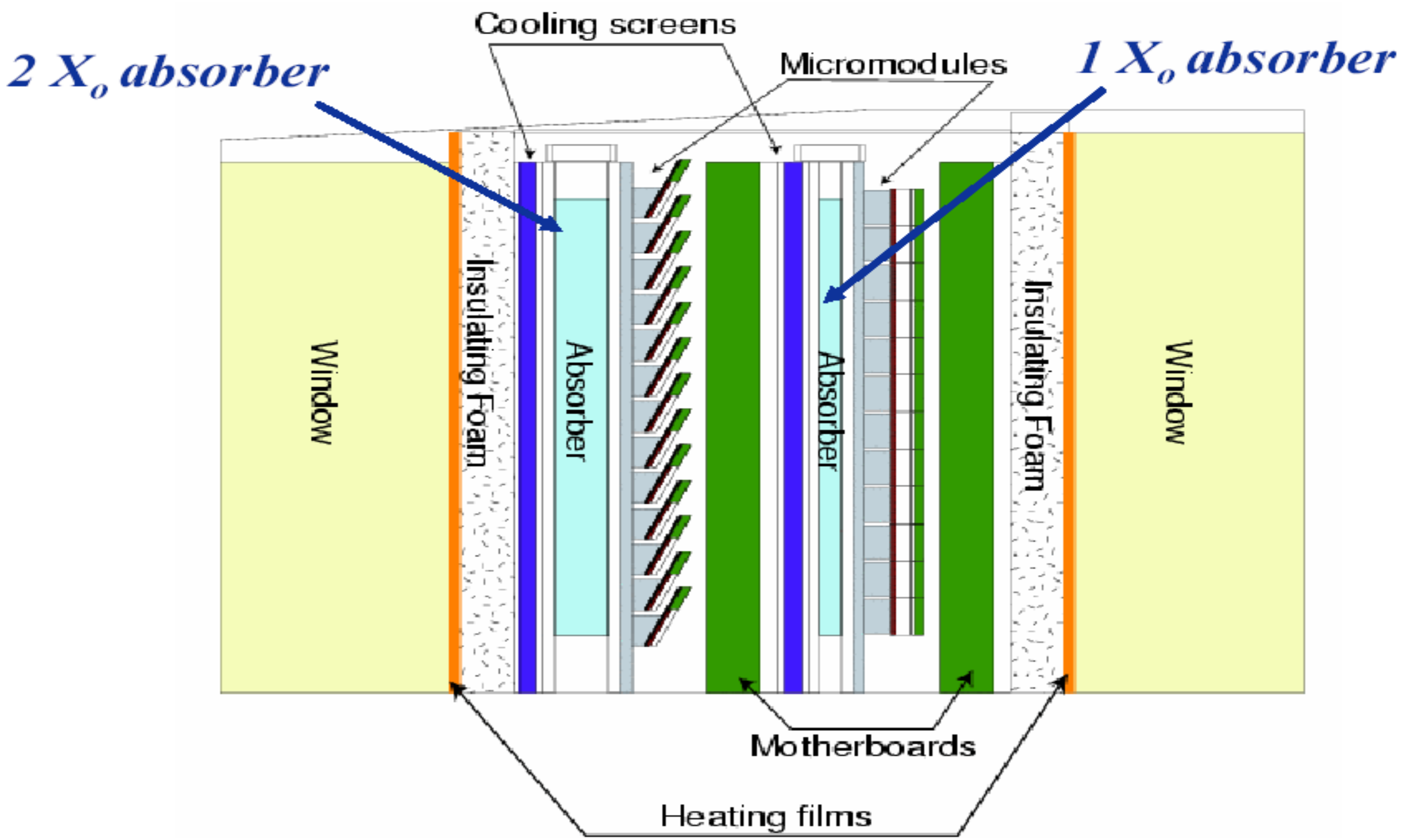
EB complete



EndCap Preshower Detector

Two-layer silicon preshower detector placed in front of the endcap calorimeters



2mm silicon strips to separate γ's from π^o's and for vertex identification.

Preshower mechanics

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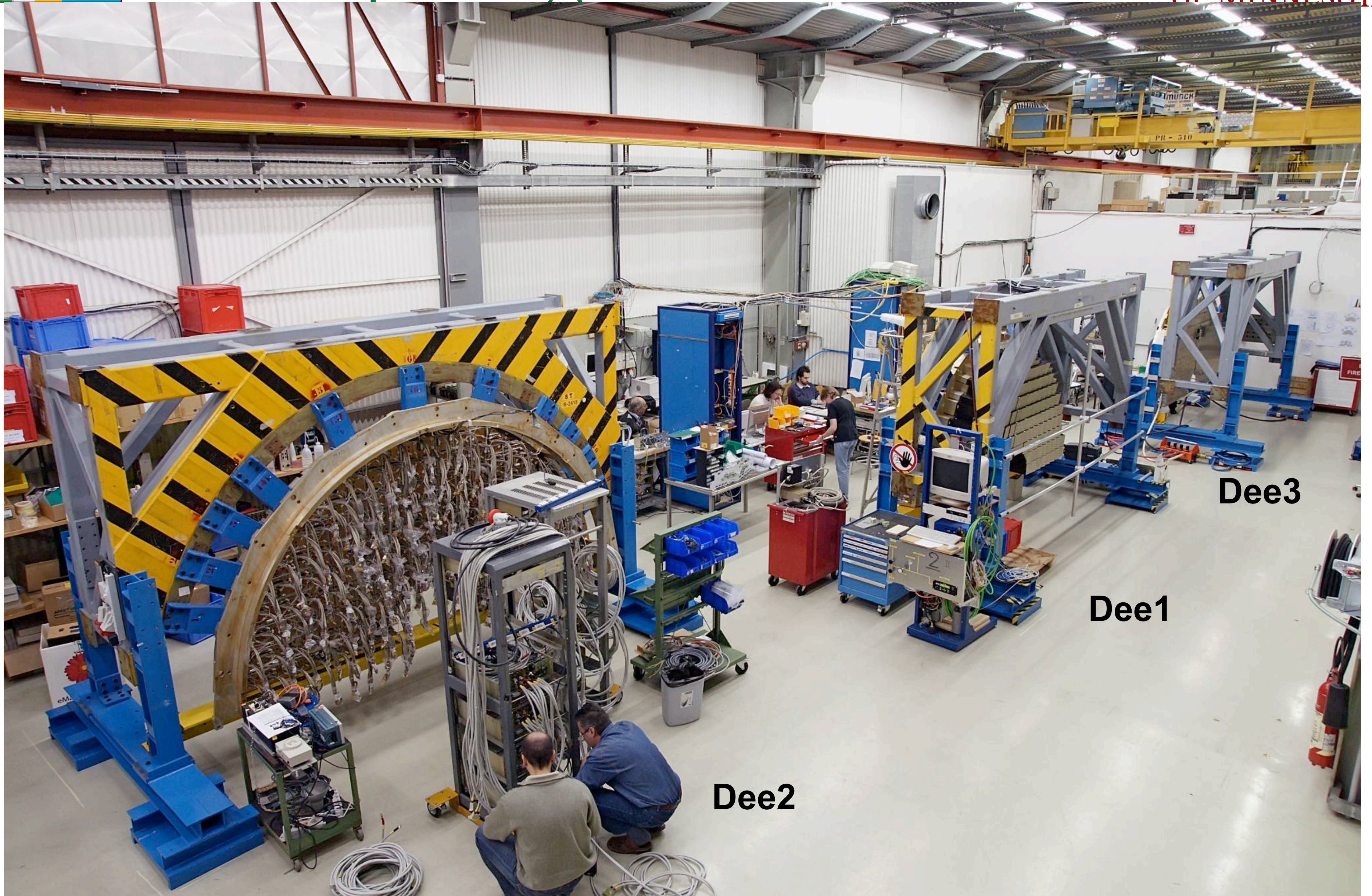
Dry assembly 2 Dees absorbers (2/08)

Rough pieces outer drum(2/7/08)

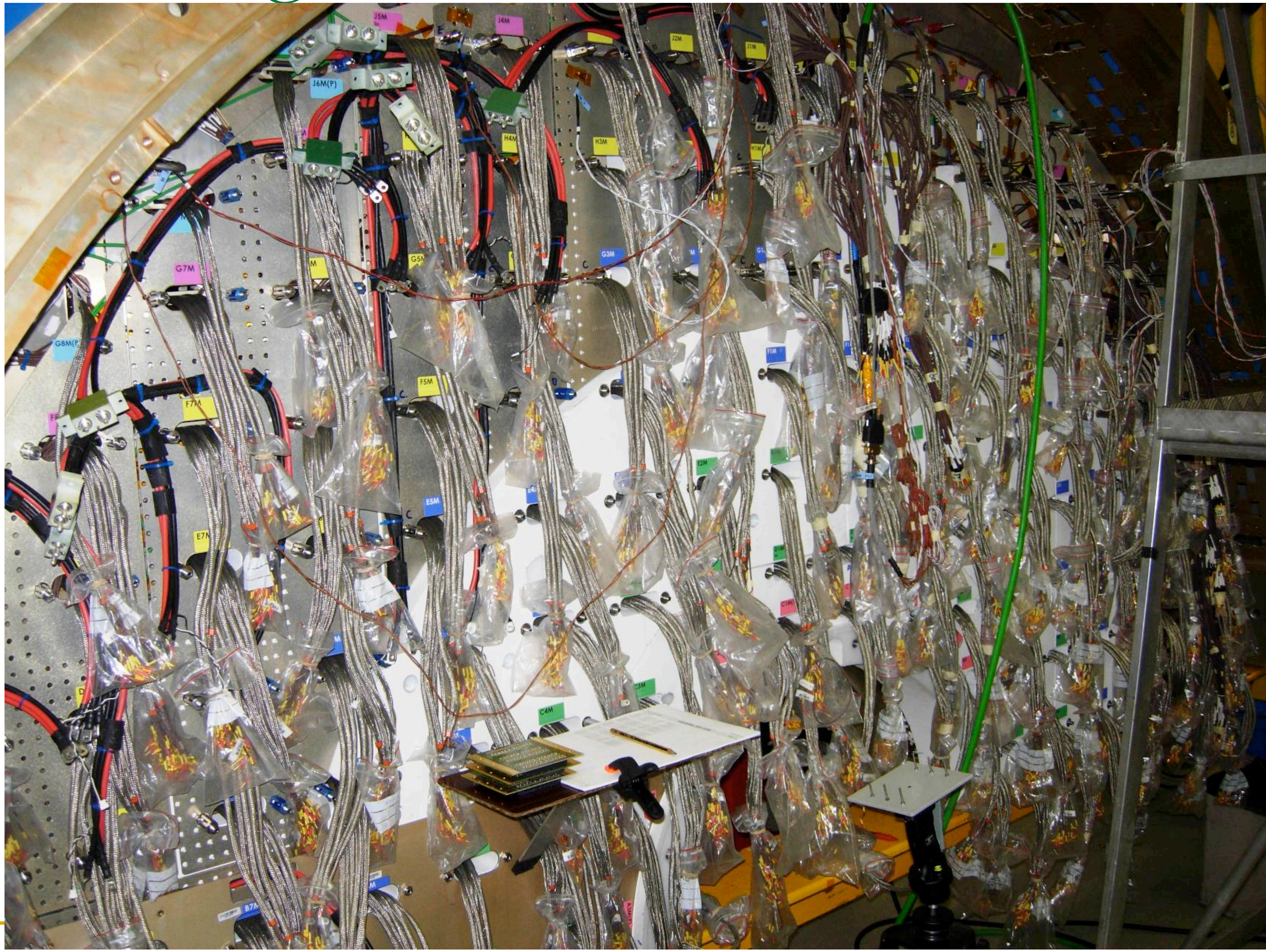
Hydraulic test screen F1(2/8/08)

First machined 1/4drum (2/15/08)

Endcap integration area



Cabling on Dee1

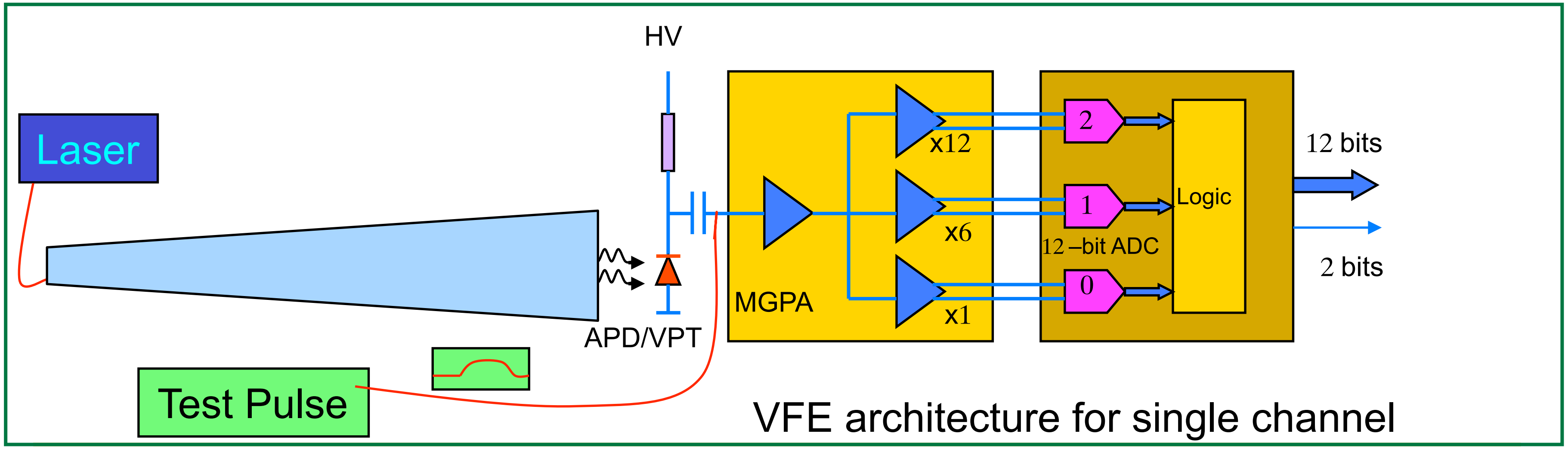


Ecal Performance

- Performance

Performance Checks

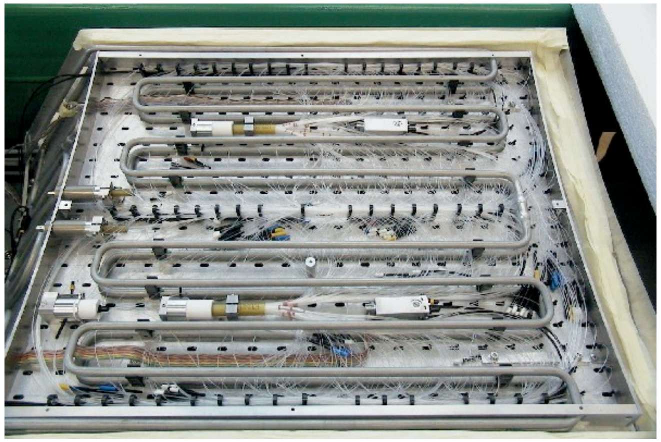
- Cross Checks
  - Test Pulse (after APD)
    - Compared to previous test pulses
  - Laser allows for self referencing
    - Compare one laser run to another



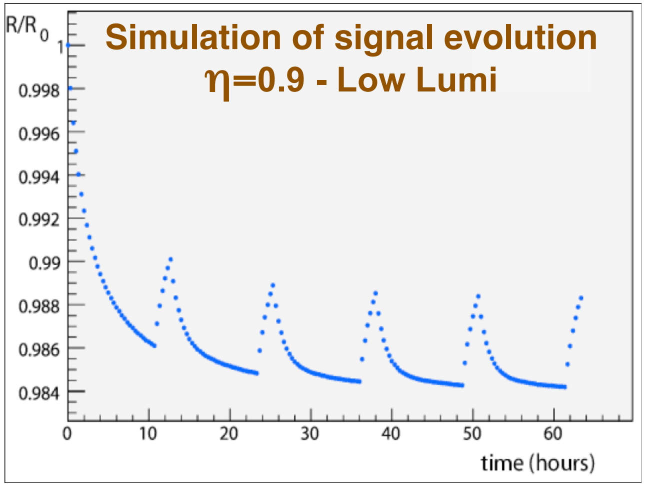
VFE architecture for single channel

ECAL monitoring system

Expected γ dose-rate on crystals at LHC high luminosity:
0.2-0.3 Gy/h (EB) → 15 Gy/h (EE)

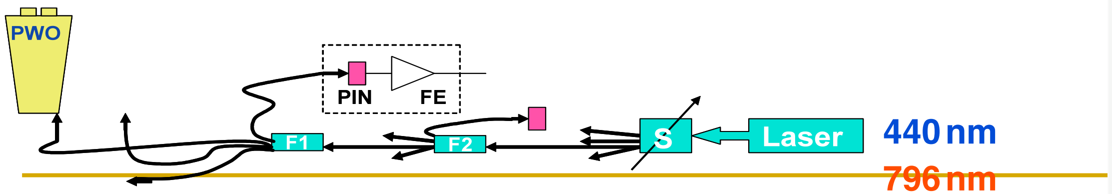


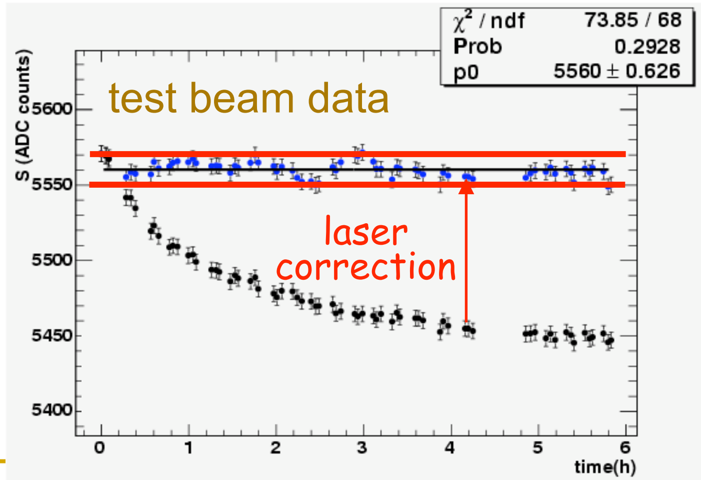
During LHC cycles, a continuous variation of signal is expected



To follow and correct, a fiber-distributed Laser system monitors the light response of each crystal

Laser fluctuations measured by PN diodes. Stability 0.1%.





Calibration

- Calibration

Energy resolution

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$$\frac{\sigma(E)}{E} = \frac{a}{\sqrt{E}} \oplus \frac{b}{E} \oplus c$$

ECAL TDR 1997

Stochastic Term

- Lateral Containment 5x5 (1.5 %)
- Photo-statistics (2.3%)
- Preshower (5%)

- Total Barrel 2.7%
- Total Endcap 5.7%

Noise Term

- Barrel 155 MeV (210 HL)
- Endcap 770 MeV (915 HL)

Constant Term

- Leakage: front, rear, dead material<0.2 %
  CMS full shower simulation
- LY Uniformity effect < 0.3%
- Temperature stabilization < 0.2%
  $\Delta T<0.05^\circ C$; @ 18 ˚C over a time interval $t \sim t_{calibration}$
  (dLY/dT = -2.0%/˚C @ 18˚C ;
  $dGain_{APD}/dT \sim$ -2.4 %/˚C)
- APD bias stabilization < 0.2%
  $\Delta V<66$ mV @ 380 V; over a time interval $t \sim t_{calibration}$
  (dGain/dV = 3.1%/V)
- Intercalibration by light injection monitor and physics signals
  (most of the energy in a single crystal goal < 0.5%)

ECAL Inter-calibration Goals

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- Energy Resolution $(\sigma_E / E)^2 = (a/\sqrt{E})^2 + (b/E)^2 + c^2$
- Goal : constant term "c" < 0.5% → $\sigma/E < 0.5\%$ (For High Energies)
- Raw crystals 15% spread.
- *In-situ* Calibrations
  - $Z \rightarrow e^+e^-$ ~few days 1% (with ϕ ring inter-calibration)
  - $W^\pm \rightarrow e^\pm\nu$ ~2 months E/p from Tracker
  - $\pi^0 \rightarrow \gamma\gamma$, $\eta^0 \rightarrow \gamma\gamma$, etc.
- Initial inter−calibrations
  - LY ~4%
  - Cosmics ~1.5%
  - Test Beam ~0.3% (Only available for 10 SM's)
- Reason for pre−calibration
  - Uniform detector response at startup

Laboratory Inter-Calibration

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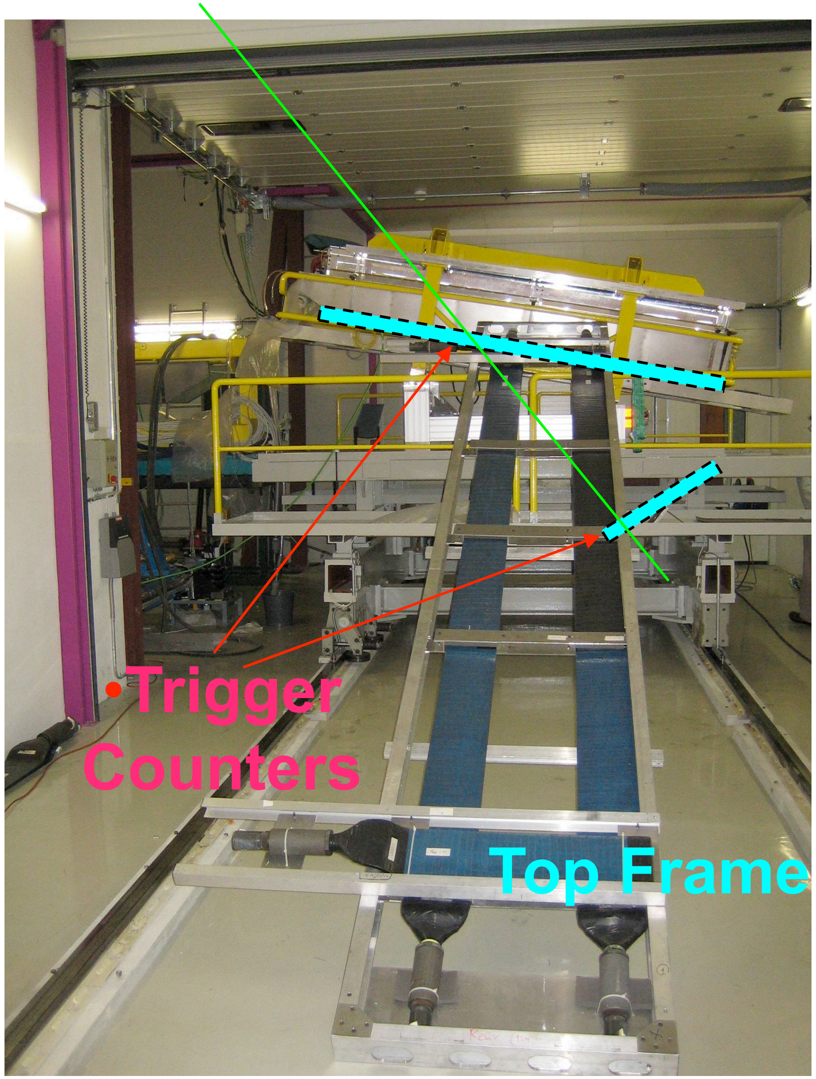
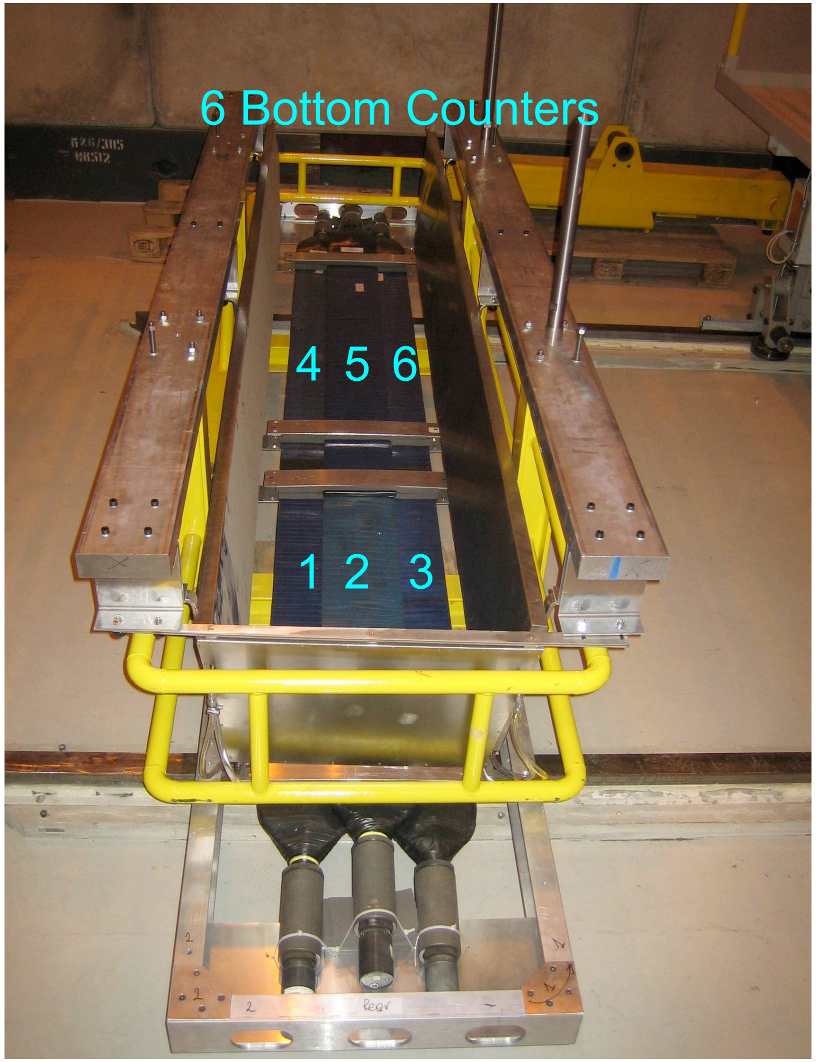
- Two current methods to LY measurements (Basically Quality Checks) automated
  - 1. Direct LY along crystal ^{60}Co
    - ~1.2 MeV source
  - 2. Transmission through crystals longitudinally at 360nm
- Combined Laboratory constants
  - Laboratory measurements are combined; LY, APD gain, the preamp.
  - Result of a ~4.0% agreement compared to testbeam calibration constants
    - Comparing ~1 MeV Source to 120 GeV testbeam!

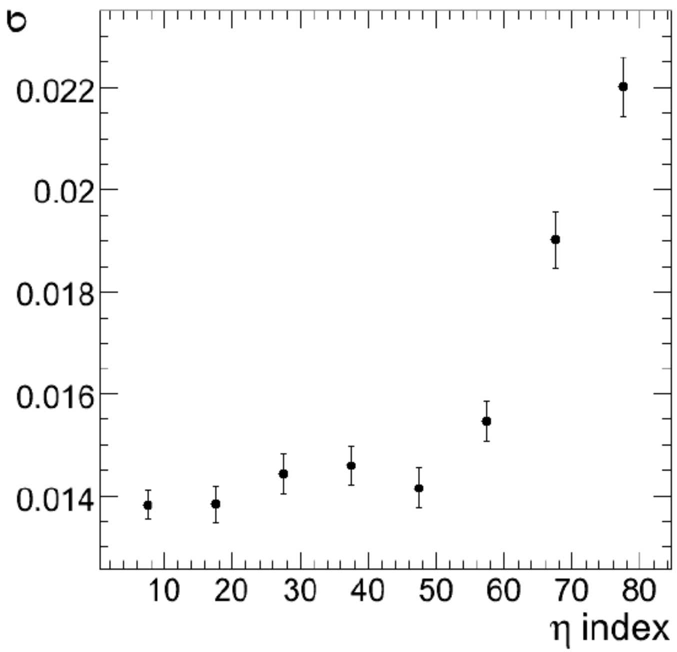
Cosmic Trigger Setup

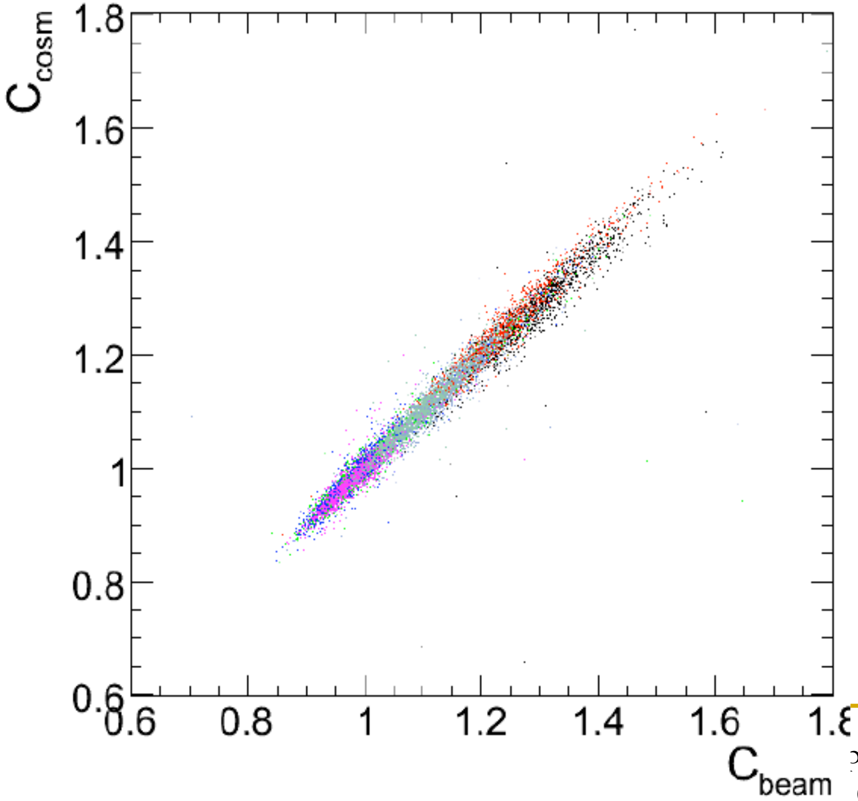


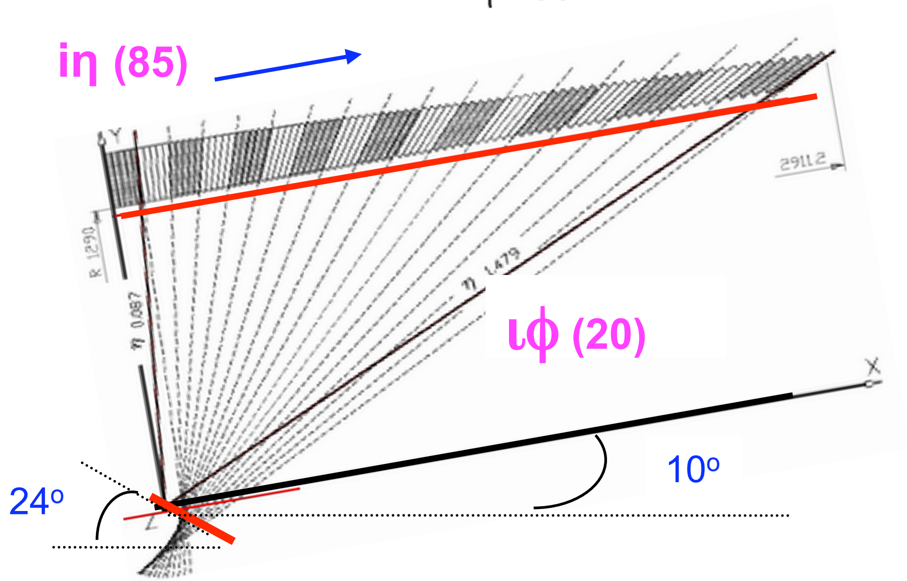


Cosmic

- 4-7 Million Triggers
- All 36 SMs have been inter-calibrated
- 1.5% overall precision





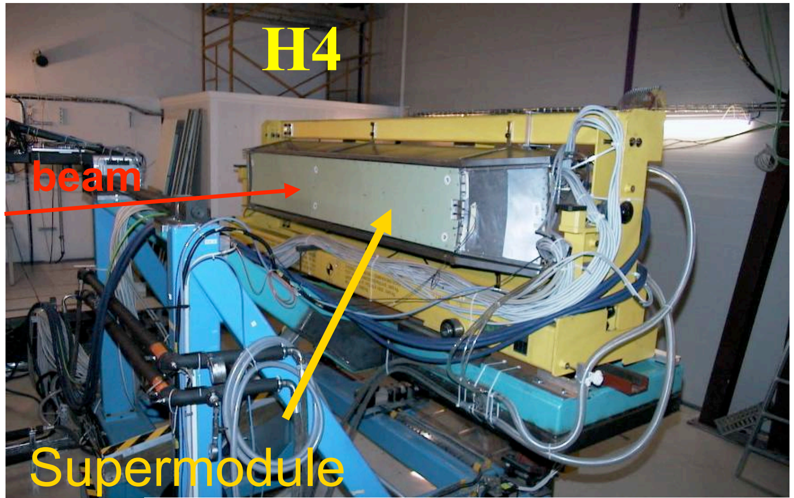


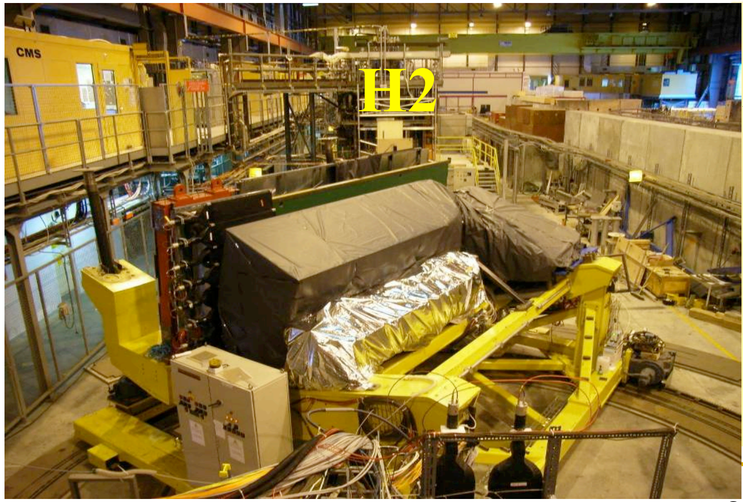
Test beam

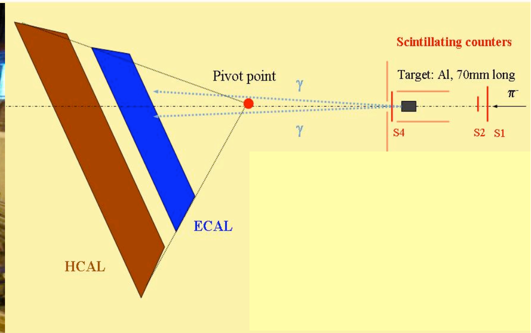
Pre-calibration with Cern-SPS high energy electron beams (from 15 GeV to 250 GeV) mandatory to understand the system

- 2004 Test-beam with 1 Super Module
(45 days of data taking; detailed system test)

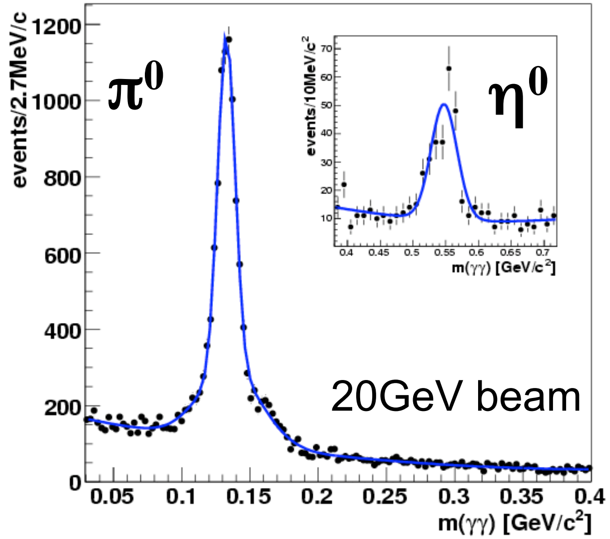
- 2006 Test-beam(s)
  - 10 SM calibrated (1 twice, 13600 xl)
  - Detailed studies E, η behaviour
  - Combined test with HCAL (1SM)







Optimize the π° reconstruction/selection



Test Beam

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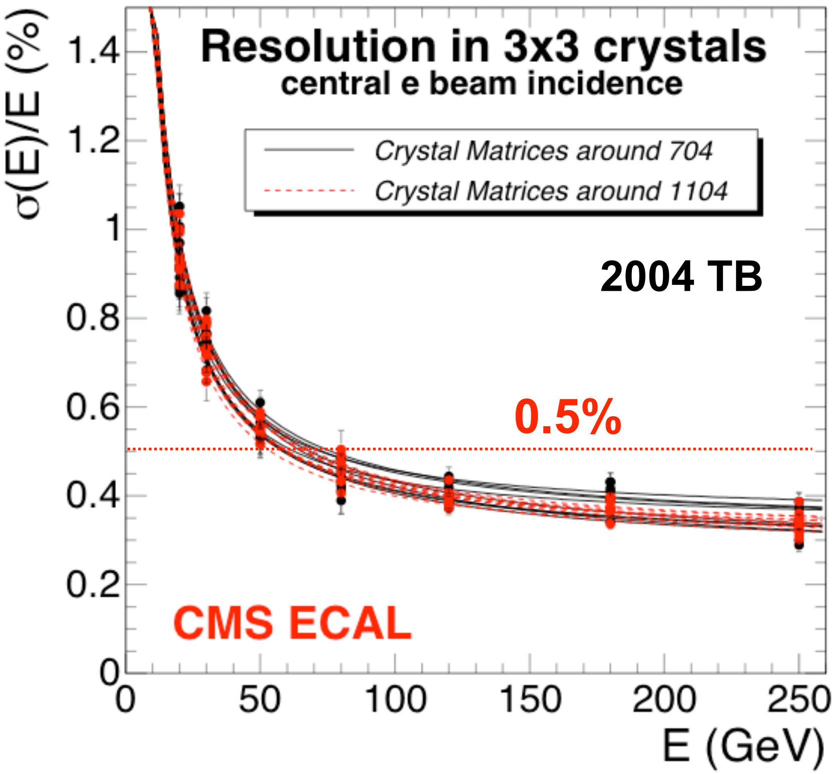
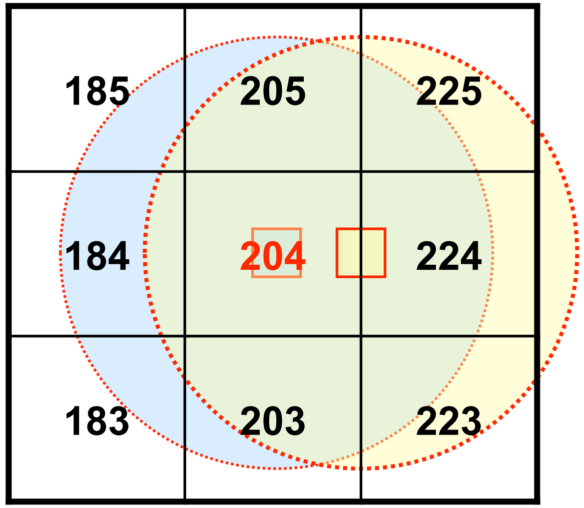
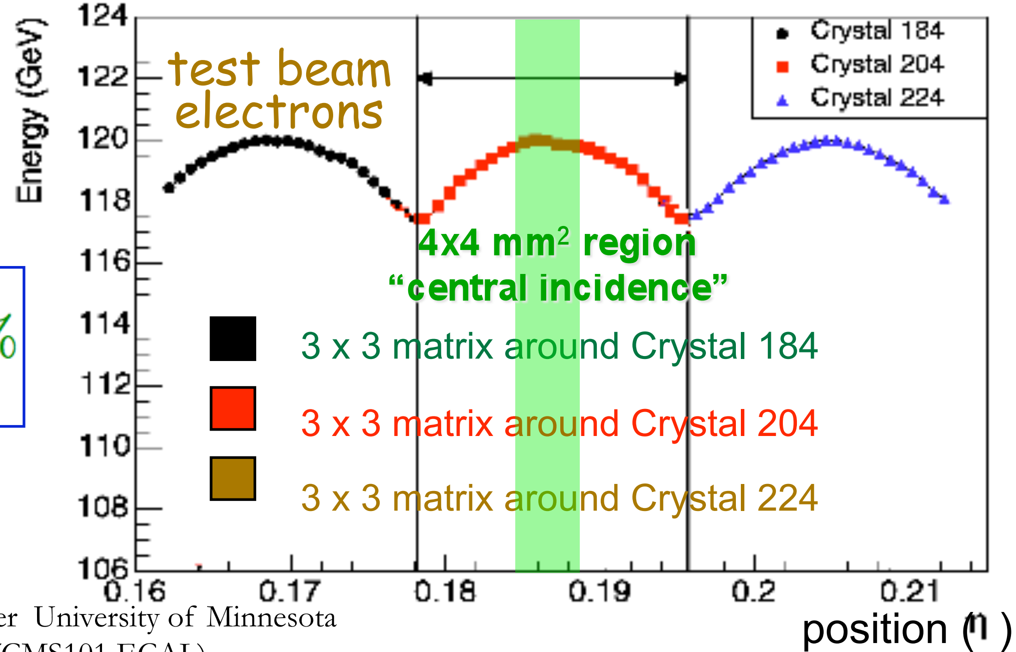


$$\frac{\sigma}{E} = \frac{2.8\%}{\sqrt{E(\mathrm{GeV})}} \oplus \frac{125}{E(\mathrm{MeV})} \oplus 0.3\%$$

Preliminary results on 2006 TB data confirm this performance





ECAL Data

- Reconstruction

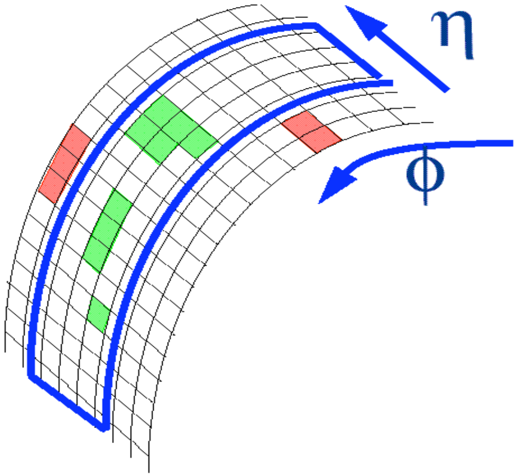
Electrons/Photons

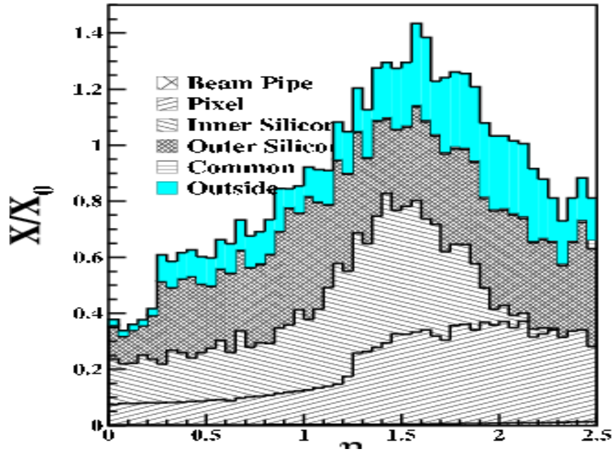
Cluster Reconstruction:

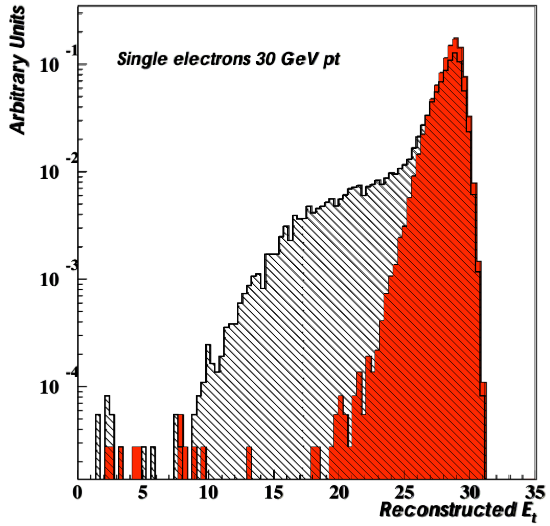
- find bumps in calorimeter
- cluster the bumps
- approximate window size $\Delta\varphi\times\Delta\eta \sim 0.8\times0.06$

Corrections:

- containment, cracks, energy loss in the tracker material







Currently Available:

Hybrid Algorithm – default in EB

Island Algorithm – default in EE

ECAL, e gamma, management

- ECAL:
  - Project Manager: Phillippe Bloch (CERN)
  - US PI's have membership of ECAL institutional board
  - Roger Rusack (Minnesota) is US ECAL manager
- Physics
  - Detector Performance Group (DPG)—calibration and commissioning: Paolo Meridiani and Giovanni Franzoni
  - Physics Object Group (POG): Chris Seez and Pascal Vanlaer

US Involvement

UNIVERSITY OF MINNESOTA

- U.S. institutions involved in ECAL include:

Caltech, Cornell, KSU, FSU, Minnesota, Notre Dame, Virginia

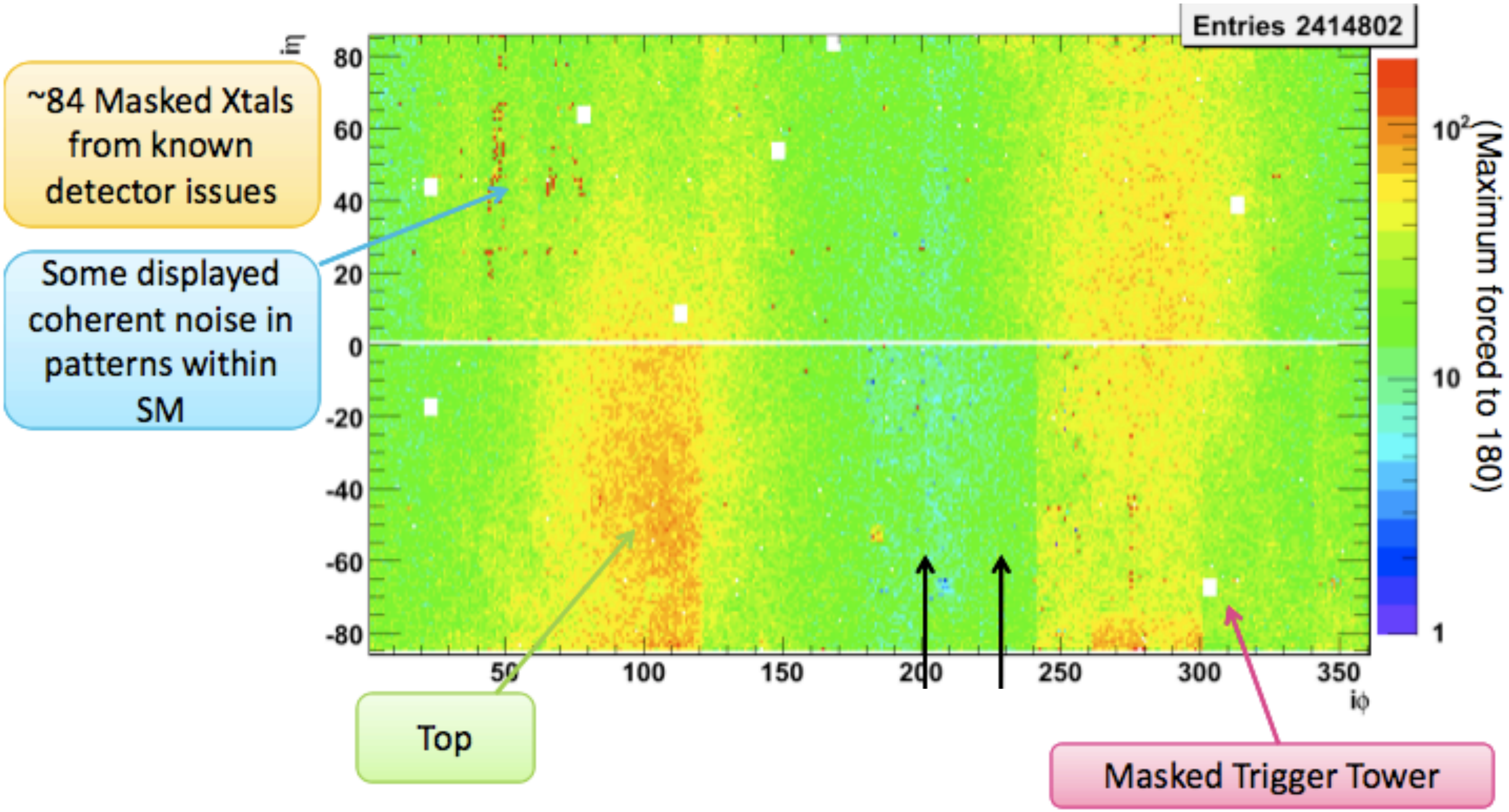
Commissioning

- CRUZET runs

CRUZET overview

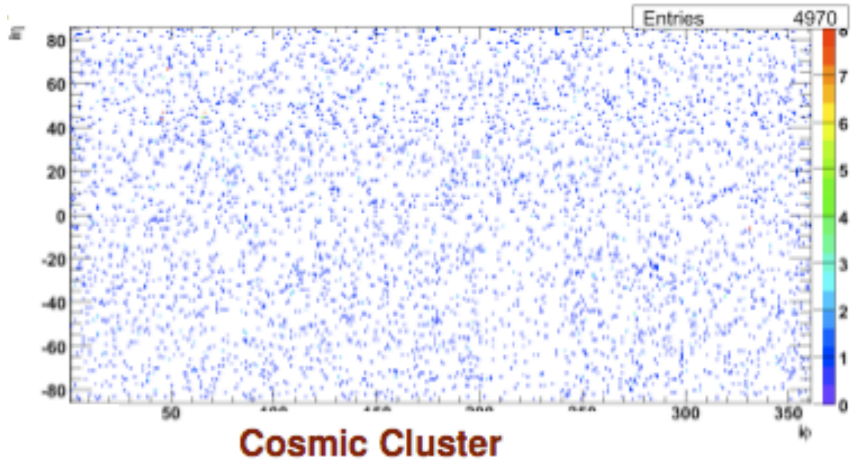
- Ecal has successfully participated in the GRUMM and CRUZET 1/2 runs (also previous global runs)
- Millions of events logged!
- As much of the detector as possible running simultaneously
- In CRUZET, all of EB read out most of the time
- Using triggers from muon system, sometimes calorimeter triggers in addition
- Also looking at calibration using dE/dx

CRUZET1 occupancy



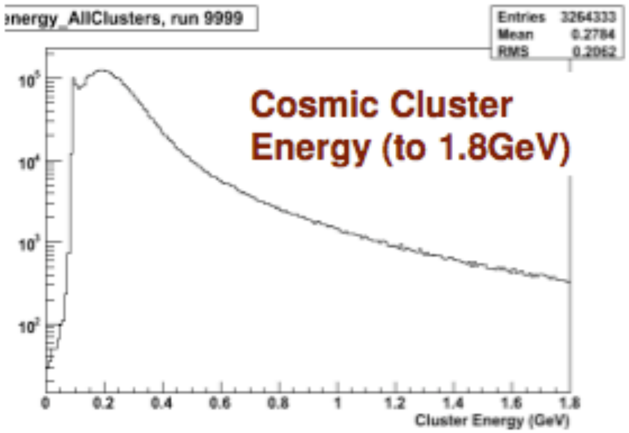
CRUZET1 energies

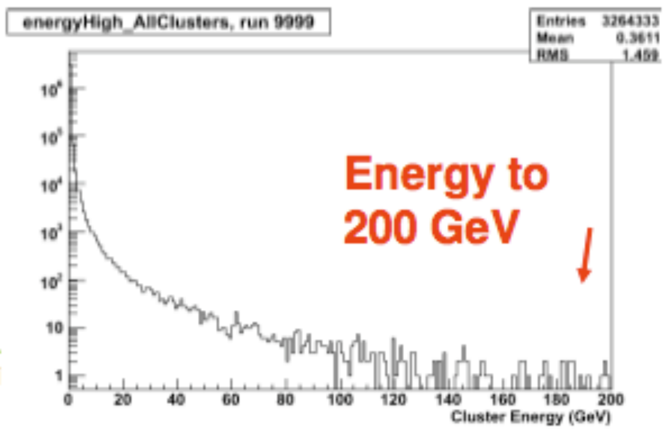
- **Energy > 10GeV**
  - ~5k clusters (2.5e-4)
- **Energy > 200GeV**
  - ~100 clusters (4e-6)



Cosmic Cluster Energy (to 200 GeV)

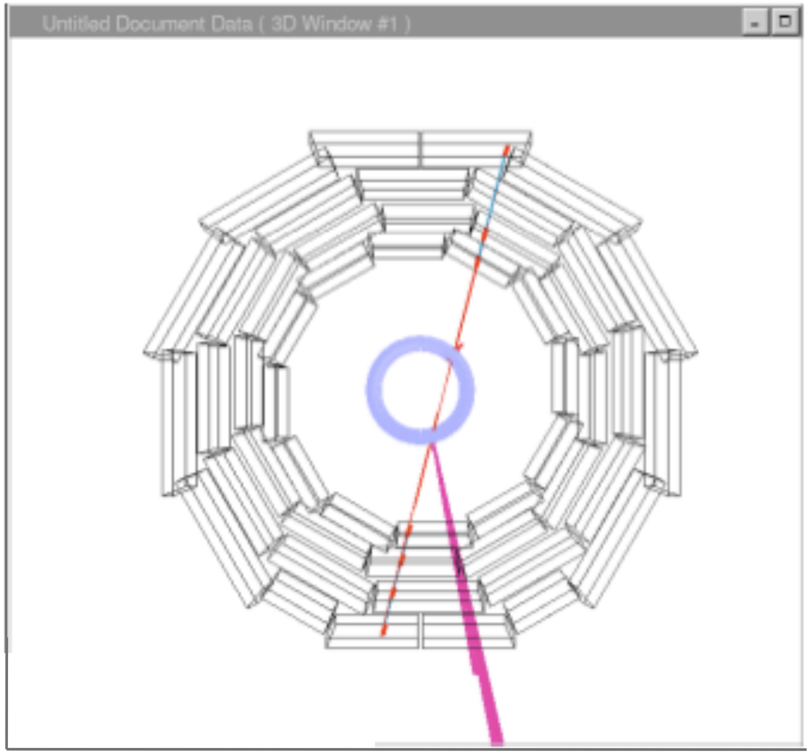
- Created "high energy" skim: events at least 1 cluster with E>10 GeV



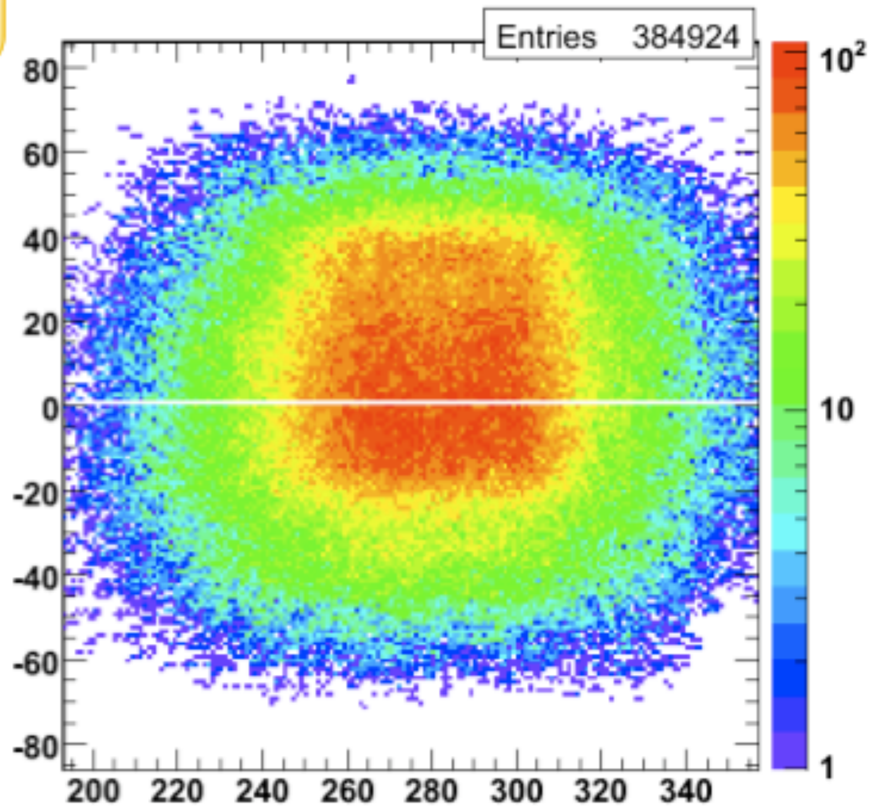


CRUZET1 track association

Single Event **Run 43566, Event 37324**
Triggered by DT: Clear association w/ DT
High Energy Event: 288 GeV, 25 crystals



Occupancy of SC seed xtals which match to a bottom track

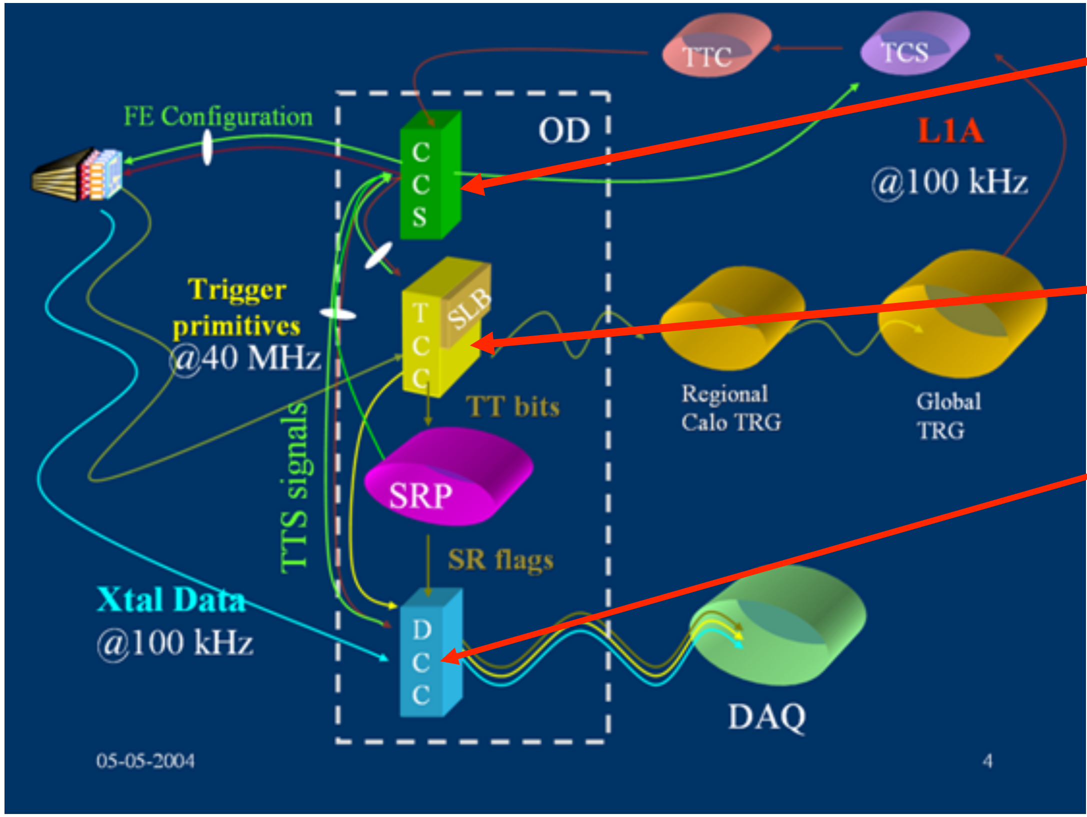


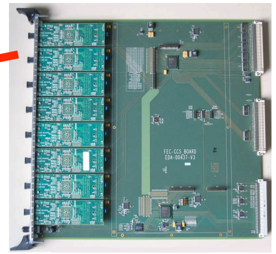
Conclusion/Summary

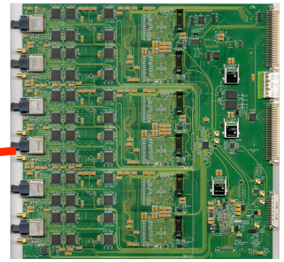
- The ECAL has performed well in tests and is calibrated
- Barrel is installed and participating in global runs (CRUZET)
  - Soon the endcaps will be ready one-by-one for installation
- Now ready to focus on the physics
  - e/gamma

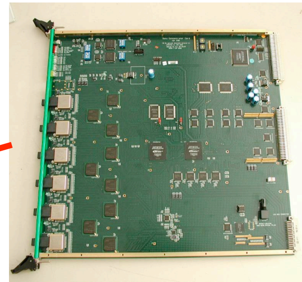
Extras

Off Detector electronics

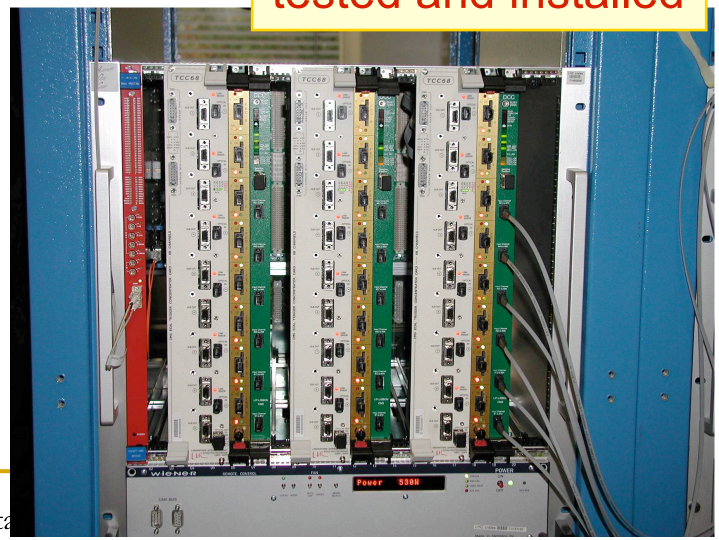








First 4 VME crates
3x(TCC;CCS;DCC)
tested and installed



- **Barrel VME modules production completed:**
  DCC (data)
  CCS (control)
  TCC-68 (trigger)
- **Endcap DCC and CCS available.**
  TCC-48 in prototyping phase.

Calibration Chain

- Crystal Energy → ADC count
  - Crystal optical response
  - APD Gain
  - Amplifier Gain
  - ADC 12bit Out